The Role of Cardiac Vagal Tone in Prediction of Individual Differences in Attention and Emotion Processing After Sleep Restriction

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Psychology

Submitted in partial fulfilment
of the requirements for the degree

Master of Arts

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Abstract

There has been increasing interest in the mechanisms by which sleep loss impacts emotion processing. Recent investigations have begun to study physiological responses to emotional stimuli following sleep loss. There is also interest in identification of individual difference markers of vulnerability to sleep loss. The current thesis examined the effect of sleep restriction on emotional processing: subjective mood, emotion regulation style (suppression and reappraisal), behavioural response to emotional task performance, and neural responses (event-related potentials) to emotionally laden visual stimuli were examined. The role of vagal tone, indexed by Respiratory Sinus Arrhythmia (RSA), was examined as a trait-like individual difference variable for prediction of vulnerability to sleep loss.

Healthy, good sleepers between the ages of 17-30 were recruited from a university population for participation in the study. The final sample of 74 participants underwent baseline ECG recording prior to random assignment to either the rested control group (C: age $M = 21.03$; men = 12) or sleep restriction group (SR: age $M = 20.49$; men = 13). All participants were well rested leading up to the experimental night when the control group had an 8 hour sleep opportunity (23:00-07:00) and the sleep restriction group had a 4 hour sleep opportunity (03:00-07:00). The day following the sleep manipulation, participants completed a number of tasks to assess the impact of sleep loss on attention and emotion. Emotional faces with varying degrees of emotional intensity were presented and were identified by expression as happy, sad, fearful, angry, or neutral; N170 event-related potentials to face stimuli were examined. Affective pictures were presented in a second task, and were identified as negative, neutral or

positive by participants; the LPP event-related potential, a measure of sustained attention was examined.

One night of sleep restricted to four hours was sufficient to lead to predictable impairments in alertness, mood, and reaction time. Regression analyses confirmed an effect of sleep loss on emotional processing that was moderated by RSA at baseline. RSA moderated the relationship between Group (SR, C) and LPP to positive affective pictures; low RSA was associated with altered processing of affective pictures due to sleep loss. RSA and use of suppression and reappraisal strategies for emotion regulation together moderated the relationship between Group (SR, C) and N170 amplitude to emotional face stimuli in sleep restricted participants.

Overall, individual differences in RSA were predictive of performance deficits on emotion processing tasks in response to a subtle degree of sleep loss that is commonly experienced. This research has implications for daily functioning, as even a single night of restricted sleep is sufficient to impact perception and response to emotional information.

Acknowledgements

There have been many people who I could never thank enough for helping me travel this road. First I want to thank my budding scientist, Janneke, who has been a wonderful helper, and my husband, Tom, who has been so patient and willing to help out whenever I asked. I could never have done any of this without the constant support of my family and friends.

I have been very fortunate to work with Kimberly Cote, who has been supportive, open, patient, and positive. I would also like to offer my thanks to Louis Schmidt and Cathy Mondloch for your support and encouragement. The Sleep Lab team has been fantastic, and I count myself lucky to have gone on this adventure with Kevin, Kari and all of the wonderful students who volunteered and worked in the lab over the last few years.

And finally to my dad, whose voice was always the loudest one in my cheering section, I miss you.

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Sleep and emotion and their combined influence on interpersonal functioning in healthy and clinical populations has become an increasingly topical issue in psychology. In their recent review on this topic, Beattie, Kyle, Espie, and Biello (2015) identified "four avenues of future research … related to 1) diverse measures of emotional functioning, 2) multi-faceted tests of social functioning, 3) role of sleep stages and circadian effects, and 4) inter-individual vulnerabilities of sleep and emotion." The present thesis fits well into the research agenda put forward by Beattie and colleagues. Literature on sleep deprivation and the cardiovascular system as related to performance, attention and emotion regulation are reviewed to introduce and frame hypotheses regarding emotional processing in response to sleep restriction, and the utility of Respiratory Sinus Arrhythmia (RSA) as an indicator of individual differences in vulnerability to sleep loss. The thesis examines outcomes from emotion processing tasks that were presented to young adults who had been restricted to four hours sleep on a single night or were assigned to a rested control group. RSA was investigated as a moderator of the effect of sleep restriction on emotion processing.

Overview of Sleep Deprivation, Performance, Attention and Emotion

In 1896 researchers began to systematically examine the effects of sleep loss on human performance; in that early study three participants demonstrated deterioration in performance from baseline measures on cognitive (memory and attention) and physical tasks. Performance deficits worsened with additional time awake in a 90 hour sleep deprivation paradigm (Patrick & Gilbert, 1896). Researchers have continued to

investigate relationships between sleep loss and measures of performance, attention, and emotion. In a meta-analysis, Pilcher and Huffcutt (1996) summarized findings demonstrating large effect sizes for both total sleep deprivation and partial sleep deprivation (sleep restricted to less than 5 hours in a 24 hour period) on measures of motor performance (e.g., time to exhaustion), cognitive function, and subjective reports of mood. In a meta-analysis of sleep deprivation research a hypothesis that attentional lapses accounted for performance deficits—rather than an overall reduction in processing capacity—was supported by the research (Koslowsky & Babkoff, 1992). Support for the lapse hypothesis was drawn from results of reviewed studies that demonstrated greater effects of sleep loss in experimenter-paced (i.e., fixed time for participant response) versus self-paced tasks, as well as greater effects of sleep loss on performance speed than accuracy. The authors proposed that attentional lapses were caused by micro-sleep episodes that diminished task performance.

Banks and Dinges (2011) summarized a debate regarding actual sleep need in humans, which concerned the conceptual division of daily sleep into two components: a core amount of necessary sleep and an optional period of additional sleep. Proponents of the existence of core and optional sleep suggested that as long as a person obtained a "core" amount of sleep (e.g. 6 hours per night), they would not suffer any consequence of sleep loss. The authors however cited evidence that healthy adults (aged 22-45) require 7.5 to 8.5 hours sleep per night; sleep restriction below that basal level resulted in detrimental effects on waking cognitive and behavioural functioning compared to rested control groups in laboratory research. It was noted that neurobehavioural responses to chronic sleep loss showed little adaptation over time, although subjective ratings of

fatigue and sleepiness did show adaptation over successive nights of restricted sleep (i.e., performance lapses on the Psychomotor Vigilance Task (PVT) increased over subsequent days in chronic sleep restriction paradigms while ratings of subjective sleepiness showed an initial increase at the onset of the sleep restriction and then quickly reached a plateau with very little change over subsequent days of restricted sleep). Studies have shown that sleep restricted to a 6 or 7 hour sleep opportunity resulted in performance deficits; however, subjective ratings of alertness were not consistent with performance decrements (Belenky et al., 2003; Van Dongen, Maislin, Mullington, & Dinges, 2003). Chronic sleep restriction has been linked to outcomes such as attentional lapses, impaired working memory, depressed mood, and perseveration of thought; notably individual responses to sleep loss have been shown to vary in a stable trait-like manner in both total sleep deprivation and chronic sleep restriction (Banks & Dinges, 2007; Rupp, Wesensten, & Balkin, 2012; Van Dongen, Baynard, Maislin, & Dinges, 2004).

Research has therefore established that sleep loss results in impairment to cognitive function in response to total sleep deprivation as well as sleep restricted to 7 hours per night or less. Performance deficits in sleep restriction paradigms do not correspond with subjective ratings of fatigue or sleepiness, indicating that caution must be used when interpreting participants' subjective state evaluations alone. Research has also supported trait-like characteristics of individual responses to sleep loss.

Sleep Deprivation and Subjective Measures of Emotion

Sleep deprivation studies have traditionally incorporated subjective mood measures, which showed a relationship between sleep loss and increased negative mood

(Pilcher & Huffcutt, 1996). For example, in a study of 39 to 66 hours of sleep deprivation, healthy young adults who were sleep deprived for one or two nights reported more intense negative mood and less intense, less frequent positive mood compared to both baseline measures and a matched control group on the Mood Scale II part of the Walter Reed Performance Assessment Battery (Paterson et al., 2011). Reports of depressed mood were more significant after two nights of sleep deprivation compared to one night; Paterson and colleagues speculated that boredom associated with prolonged time in the laboratory setting during sleep deprivation studies may be a significant contributor to reported increases in depressed mood.

In a sleep restriction paradigm wherein healthy young adults had their sleep restricted to 4-5 hours for 7 consecutive nights (a reduction of 33% from their habitual sleep time), participants noted increased cognitive, emotional, and somatic complaints from day 3 of the sleep restriction week until the end of the study (Dinges et al., 1997). Scores were elevated on subjective sleepiness ratings, Profile of Mood States (POMS) subscales for fatigue, confusion, tension, and total mood disturbance, and visual analog scale (VAS) ratings of mental exhaustion and stress, as well as diary-type lists of somatic complaints. The authors proposed that increased complaints from participants in these areas may have been a function of stress, as participants were required to expend more effort in order to compensate for increased levels of sleepiness as the week progressed. A suggestion was made that chronic sleep restriction may lead to different outcomes on affective measures than total sleep deprivation.

The relationship between sleep loss and emotion is thought to be a function of reduced functionality in neural networks that typically regulate emotional states, as well

as impaired encoding of emotional memories during sleep, which may impair the processing of emotional material in subsequent waking periods (Kahn, Sheppes, & Sadeh; Walker & van der Helm, 2009). Walker (2009) presented a model wherein sleep loss resulted in blunting of subsequent positive emotional events or activities, while the emotional response to negative emotional events or activities was enhanced. Zohar, Tzischinsky, Epstein, and Lavie (2005) followed medical residents as they coped with positive and negative emotional events at work. The authors found that when medical residents were sleep deprived during a night shift at a large hospital, their emotional response to negative events was magnified and they did not report increased positive affect after they experienced positive events. In the rested condition of the within subjects design, the medical residents demonstrated less emotional responsiveness to negative events, and reported increased positive affect in response to positive events.

It has been hypothesized that sleep deprivation lowers the threshold at which an event is considered stressful and becomes associated with increased negative affect, which may be related to difficulty with cognitive task demands during sleep deprivation (Minkel et al., 2012). Researchers used a 48-hour total sleep deprivation design to assess responses to high and low stress tasks. Subjective reports of stress, anger and anxiety were elevated in the sleep deprived group compared to a rested control group on the low stress task only; in response to the high stress task there were no group differences on those dimensions.

van der Helm, Gujar, and Walker (2010) used pictures of human faces expressing emotional states (i.e. happy, sad, angry) in order to assess the ability of healthy young adults to recognize emotional information during a 30-hour total sleep deprivation

condition and after recovery sleep; the task was also administered to a rested control group. Blocks of 10 pictures were presented consisting of one emotion in a range from fully neutral to fully emotional, with a 4-choice descriptive rating scale: “definitely neutral; more neutral than happy; more happy than neutral; definitely happy”. Participants in the sleep deprivation condition rated the emotional faces as more neutral in the mid-range of expression (i.e. between the fully neutral and fully emotional face). When the ratings were broken down by emotional expression, happy and angry faces showed significant differences in ratings, while no differences were identified in the intensity ratings for sad faces. The authors interpreted the findings to suggest that sleep deprivation caused emotional blunting that adversely impacted the ability of sleep deprived participants’ ability to identify salient social cues.

Using the International Affective Picture System (IAPS: Lang, Bradley & Cuthbert, 2008) researchers have noted a tendency for sleep deprivation to be associated with a bias towards negative emotional evaluations. For example, in one study utilizing blocks of positive, negative, and neutral IAPS pictures, undergraduate students who were sleep deprived for one night rated neutral pictures as more negative than did control participants and reported increased negative mood compared to rested controls (Tempesta et al., 2010).

Sleep loss has also been linked to aggression and violence in correlational studies. A recent review highlighted correlational evidence of a relationship between aggressive behaviour in clinical samples and reports of poor sleep (Kamphuis, Meerlo, Koolhaas, & Lancel, 2012). The authors present a hypothesis that an individual’s vulnerability to the effects of sleep deprivation may be linked to the development of aggressive and violent

behaviour patterns through poor pre-frontal cortex functioning. In an experimental design, healthy young men participated in a task designed to measure aggression in response to provocation during game play; sleep deprived participants (awake for 33 hours) demonstrated reduced aggression in comparison to rested controls (Cote, McCormick, Geniole, Renn, & MacAulay, 2013). Behavioural data in this study was shown to be consistent with reduced levels of testosterone, but not cortisol, in sleep deprived males. The relationship between aggression and violence and sleep loss needs further investigation in order to clarify under what circumstances sleep loss enhances or diminishes aggressive behaviour.

Killgore et al. (2008) used a measure of emotional intelligence to study the impact of 55.5-58 hours of total sleep deprivation on emotional functioning. Healthy, young adults completed measures of emotional intelligence at rested baseline and after sleep deprivation. The reported findings were described as consistent with impaired prefrontal cortex functioning with sleep deprivation: deficits were identified after sleep deprivation in intrapersonal (self-regard, assertiveness), interpersonal (empathy, interpersonal relationships), stress management (impulse control), and constructive thinking (behavioural coping).

This research shows that both total sleep deprivation and sleep restriction have an impact on affective functioning, related to subjective self-report of mood and behavioural responses on affective tasks such as recognition of human emotional facial expressions. However, as noted previously, subjective reports of sleepiness and fatigue do not correspond well with behavioural changes in chronic sleep restriction paradigms. It follows that subjective mood should not be examined in isolation, but in conjunction with

psychophysiological measures in order to identify neurocognitive changes with sleep deprivation that may account for observed alterations in affective state or behavioural outcomes on emotional processing tasks.

Sleep Deprivation and Objective Measures of Emotion Processing

Researchers have begun to utilize psychophysiological measures and imaging techniques to clarify the relationships between sleep loss, affective state, and subjective ratings of emotional material, as described above. Researchers utilizing fMRI proposed to examine medial-prefrontal cortex (mPFC) top down inhibitory control over the amygdala during an emotional picture viewing task during sleep deprivation; the study was designed in light of previous research that supported the role of these brain regions in processing of emotionally salient material (Yoo, Gujar, Hu, Jolesz, & Walker, 2007). fMRI measures of cortical activation were evaluated by comparison of a 35 hour sleep deprivation group with a rested control group of healthy young adults (aged 18-30). Participants viewed negative and neutral IAPS pictures presented in a pseudorandom order from neutral to increasingly aversive. Researchers noted that amygdala activation was similar in control and sleep deprived participants when viewing neutral pictures; however, when viewing negative pictures, amygdala activation for the sleep deprivation group was significantly greater. Control participants demonstrated greater connectivity between the medial prefrontal cortex (mPFC) and the amygdala compared to the sleep deprived group; the sleep deprived group demonstrated significantly greater connectivity between the amygdala and brainstem regions during processing of emotional material. These findings were interpreted as a failure of top-down prefrontal control in the sleep deprivation group. In a subsequent fMRI study by the same group, cortical activation to

viewing pleasant and neutral images from the IAPS picture set was assessed in a 32 hour sleep deprivation group and a rested control group (Gujar, Yoo, Hu, & Walker, 2011). Pictures were presented along a gradient from most neutral to most positive; participants were asked to push a button to rate each picture as "neutral" or "positive". In contrast to studies showing blunted response to positive stimuli with sleep loss, sleep deprived participants rated pictures as more pleasant than controls overall. Consistent with their previous study, a pattern of reduced connectivity between the amygdala and mPFC in sleep deprived versus rested control participants was reported, along with increased activation in the amygdala along with mesolimbic areas including the VTA of the brainstem in sleep deprived participants compared to rested controls. The authors concluded that sleep deprivation resulted in increased emotional reactivity to both positive and negative stimuli. These two studies provide evidence for differential neural activation in response to emotionally valenced stimuli, which may account for differential behavioural outcomes on affective tasks in sleep deprivation versus rested controls.

Franzen, Buysse, Dahl, Thompson, and Siegle (2009) used an autonomic nervous system (ANS) measure of pupillary reactivity to examine responses to negative, neutral and positive IAPS pictures that were presented in blocks to a 31-33 hour sleep deprivation group and a rested control group. Pupil dilation was used as a measure of cognitive and affective information processing; pupil dilation has been shown to occur with attentional allocation, in response to emotional information, and in response to cognitive load. Subjective ratings of the pictures on a 9-point scale from "very pleasant" to "very unpleasant" did not differ between the sleep deprivation and control group in this study. Increased pupillary response was noted in the sleep deprived participants

compared to control participants during viewing of negative pictures. Sleep deprived participants also demonstrated increased pupillary response during the warning cues in the negative picture presentation block. This study provided evidence for ANS reactivity to negative emotional visual content as a result of sleep deprivation.

In an event-related potential (ERP) study of emotional facial expressions (happy, sad, angry, and fearful), Cote, Mondloch, Sergeeva, Taylor, and Semplonius (2014) reported a preferential impact of sleep loss on the processing of emotional faces. Specifically, the N170 ERP, a neural marker of face processing, was the same for happy faces, reduced to sad faces, yet larger for angry and fearful faces in sleep deprivation compared to control. This is evidence for blunted neural response to sad faces and a reactive neural response to threat-relevant faces as a result of sleep deprivation. ERP responses to emotionally valenced pictures from the IAPS picture set were also found to be altered after one night of sleep deprivation in healthy, young adults (Cote, Janscar, & Hunt, 2015); larger Late Positive Potential (LPP) ERPs, markers of sustained attention, were reported to emotional (negative more so than positive) pictures but not neutral pictures in the sleep deprivation group relative to controls. This provides further evidence for altered neural processing of emotional information associated with sleep loss.

Overall, these studies show a pattern of differential neural processing that supports altered processing of emotional stimuli with sleep loss that must be examined in the context of the nature of the emotional material used (i.e., positive, negative, happy, sad, neutral).

Overview of Event Related Potentials in Relation to Affective Stimuli

Research has shown that neural responses to visually presented emotionally valenced stimuli can be examined with ERPs (Hajcak, MacNamara, & Olvet, 2010; Olofsson, Nordin, Sequeira, & Polich, 2008). In a review of the neural processes involved in face perception, Palermo and Rhodes (2007), identified the N170 ERP component as a measure of cortical activation to visually presented face stimuli. Research showing early response to face stimuli was summarized citing studies using EEG and MEG which quantified the rapid time course of face processing. Faces have been found to be processed more rapidly than objects or words; additionally, there is evidence that threat-related faces are processed preferentially. A theoretical explanation for the preferential treatment of threat faces states that rapid amygdala activation occurs with detection of threat faces by the visual cortex, while executive attentional control is engaged via indirect pathways between the amygdala and cortical visual processing areas in the vmPFC and the dlPFC. The N170 has been described as maximal at lateral occipital sites in response to visual face stimuli and represents structural encoding of faces (Eimer & Holmes, 2007). In a recent study, N170 response to emotional face stimuli was enhanced for participants with higher scores on a measure of empathy (Choi et al., 2014). These results were interpreted as more attention to emotional faces in the high empathy group.

Research examining the LPP to emotional pictures has shown consistently larger ERP responses to emotional pictures, particularly stimuli characterized by negative valence and/or high arousal compared to neutral or low arousal stimuli (Olofsson et al., 2008; Schupp et al., 2004; Smith, Weinberg, Moran, & Hajcak, 2013). The LPP has been shown to be enhanced by motivated attention in contrast to passive viewing, and has been

linked to maintenance of information in working memory (Hajcak et al., 2010; Schupp, Flaisch, Stockburger, & Junghofer, 2006). Functionally, the utility of an enhanced LPP to emotional stimuli has been thought to reflect selective, motivated attention to the stimuli, with consequent reduction in attentional resource availability for new stimuli (Brown, van Steenbergen, Band, de Rover, & Nieuwenhuis, 2012). The LPP has been related to activation of the extrastriate visual cortex, lateral occipital cortex, parietal cortex, and inferior temporal cortex (Lang & Bradley, 2010). In summary, the LPP, which has been shown to be maximal at central-parietal sites (e.g., Pz) in response to affective picture viewing, is larger in response to emotional and arousing pictures (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000).

Thus ERP responses to emotional material provide a meaningful measure of neural functioning that aligns well with investigation into the effects of sleep loss on objective measures of emotion processing.

Overview of Cardiac Correlates of Cognitive Performance, Attention and Emotion

The vagus nerve (cranial X) is the nerve via which information passes between the brain and the lower head, throat, neck, chest, and abdomen (Parker, 2009). This nerve conducts information between neural structures (including the central nucleus of the amygdala, the anterior cingulate and the ventromedial prefrontal cortices) and the pacemaker of the heart, the sinoatrial node, via the stellate ganglia and vagus. This bidirectional pathway has been related to neural networks implicated in attention and emotion regulation (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Vagal tone is considered a peripheral nervous system (PNS) measure of an individual's capacity for

effective coordination of cardiac, affective, attentional and behavioural responses in pursuit of goals or in order to adapt to the environment (Thayer & Lane, 2000). Respiratory sinus arrhythmia (RSA) or high frequency (HF) variability in beat-to-beat variations in the heart rate (heart rate variability: HRV) is considered a reliable measure of cardiac vagal tone (Berntson et al., 1997; Grossman & Taylor, 2007). In neuroimaging studies, HF HRV power has been associated with blood flow to the ACC, right dlPFC, dmPFC, and amygdala, among other regions (Napadow et al., 2008; Thayer et al., 2009). It is also associated with task performance on executive function tasks, and with attention regulation and response inhibition (Thayer et al., 2009). HF HRV reactivity (RSA_{task}-$RSA_{baseline}$) has been utilized as a measure of vagal withdrawal in response to psychological challenge (i.e. during a mental arithmetic task or with video game play) or in response to a psychological stressor (Cacioppo, Uchino, & Berntson, 1994). Excessive vagal withdrawal in response to emotional challenge has been associated with poor emotion regulation (Beauchaine, 2015).

Waking measures of HRV have been shown to be stable in adult, adolescent, and childhood samples. El-Sheikh (2005) reported stable individual differences in resting baseline RSA as well as RSA reactivity to a stressor by children aged 6 to 13 who were tested at baseline and then 2 years later in a longitudinal study. Kleiger and colleagues (1991) and Pitzalis and colleagues (1996) both reported stability in heart rate variability measures in normal, healthy subjects over time (65 days and 7 months respectively).

Research has therefore established relationships between frontal neural structures and beat-to-beat variability in the electrocardiogram (ECG) that can be indexed by HF

HRV. HF HRV has been understood to be a trait-like individual difference measure related to cognitive performance, attention, and emotion regulation.

Heart Rate Variability and Emotion Regulation

High resting HF HRV has been associated with resilience in children living in high risk environments, while low resting HF HRV has been associated with behavioural problems such as conduct disorders, attention disorders, and depression in children (Pang & Beauchaine, 2013). In adolescents and adults, low HF HRV has been associated with aggression and antisocial behaviour, depression, anxiety and panic disorders (Beauchaine, 2001). Beauchaine (2001) posited that reduced RSA (a measure of HF HRV) was associated with dysregulated affective style throughout the lifespan; and in a recent review, presented RSA as a useful marker of PFC dysfunction, accounting for associations between low RSA and poor behavioural control in psychopathology (Beauchaine, 2015). In a meta-analysis, Thayer and colleagues (2012) proposed that high HRV was a marker of effective emotional self-regulation characterized by a smaller negativity bias (the tendency to prioritize negative information over positive information), and greater willingness to approach novel objects. They suggested that high HRV was related to context appropriate responding to events as well as superior physiological recovery after the occurrence of a stressor.

In a recent review, Park and Thayer (2014) summarized evidence suggesting that higher HRV was associated with more effective top-down and bottom-up processing of emotional stimuli, while lower HRV was associated with impaired top-down processing resulting in a maladaptive reliance on bottom-up processing in response to emotional

stimuli. Resting HRV has been related to inhibitory inputs from the vagus, and has been associated with inhibitory prefrontal subcortical circuits in imaging studies reviewed. The authors suggested that the relationship between high HRV and effective prefrontal neural functioning accounted for relationships reported in the literature between high HRV and faster and/or more accurate responding on a variety of tasks including tasks designed to test executive cognitive functioning, as well as associations with superior emotion regulation abilities. As an example of an association between high HRV and performance on affective tasks, a recent study by Quintana, Guastella, Outhred, Hickie, and Kemp (2012) found HF HRV to be a significant predictor of performance on an emotional recognition task where participants were asked to identify the emotion conveyed in a picture where only the model's eyes were visible (Reading the Mind in the Eyes Test: RMET). In an ERP study, high RSA at baseline was associated with differential processing of emotional pictures from the IAPS set (Dufey, Hurtado, Fernandez, Manes, & Ibanez, 2011); group (high/low RSA) differences were identified for early (P1), middle (EPN), and late (LPP) latency ERP components to emotional pictures. Larger LPP responses to all stimulus categories were noted in the high relative to the low RSA group, which was interpreted as evidence of differential modulation of attention during the picture viewing task. In an emotional stop signal task, an interaction was found between high and low HRV and responses to both "go" and "stop" trials, where HF HRV was associated with better performance (response time) on trials with negative emotional stimuli, and no group (high/low HRV) differences were found for trials with neutral stimuli (Krypotos, Jahfari, van Ast, Kindt, & Forstmann, 2011). These results were

interpreted as relations between high HRV and the ability to shift attention away from negative emotional distractors.

Fabes and Eisenberg (1997) studied adults as they coped with daily stressors. Higher baseline vagal tone was associated with less frustration in response to daily stressors when the stressors were rated as moderate to high; these participants tended to employ more constructive coping mechanisms (i.e. problem-focused coping rather than avoidant coping). There was little difference in management of low level stressors between the high and low vagal tone groups. It was concluded that vagal tone may be an internal marker of individual difference in regulatory control, and may therefore be related to individual responses to stressful events. Kogan, Allen, and Weihs (2012) found that baseline RSA in women undergoing treatment for breast cancer was predictive of stress reported one year later. Higher baseline RSA as a measure of emotional regulation ability was thus associated with more effective adaptation to stress associated with cancer treatment.

These studies provide evidence for a relationship between high HRV and effective self-regulation of emotional states, particularly in high stress situations, that has been linked to pre-frontal neural functioning in neuroimaging studies.

Heart Rate Variability and State/Trait Measures of Personality and Affective Style

RSA has been related to state and trait anxiety (Fuller, 1992; Miu, Heilman, & Miclea, 2009; Thayer & Lane, 2007; Watkins, Grossman, Krishnan, & Sherwood, 1998). Fuller (1992) examined self-report and psychophysiological data from women who were identified as low on trait anxiety, high on trait anxiety, or repressors (self-reported low

trait-anxiety and demonstrated psychological responses typical of high trait-anxiety). He related that "truly" low anxious women demonstrated higher RSA compared to high anxious women or repressors, and this relationship did not change across a 3 week period wherein graduate students completed a highly stressful oral examination. Watkins and colleagues (1998) studied a subset of healthy adults (age 25-44) who scored either high (n = 23) or low (n = 22) on a measure of trait anxiety, the Spielberger State Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants whose score reflected high trait anxiety showed a 36% reduction in baroreflex control and an 8% reduction in RSA when compared to the low trait anxiety group. The authors noted that reductions in RSA corresponding with trait anxiety were relatively small, but were significant. The researchers concluded that there was a relationship between reduced vagal control of the heart and high trait anxiety that may account for the relationship between anxiety and sudden cardiac death. Miu, Heilman, and Miclea (2009) examined healthy volunteers with high or low trait anxiety scores on a self-report inventory; high trait anxiety was associated with lower HF HRV power across mental stress and autogenic relaxation conditions. State anxiety after a mental stress task demonstrated a negative correlation with HF HRV power. Taken together, the research supports HF HRV as an index of emotional self-regulatory ability in relation to state and trait measures of anxiety.

In a review of the research on cardiac vagal tone and depression, Rottenberg (2007) criticized the literature, citing small to medium effect sizes predominated in the research reviewed. Depression accounted for only approximately 2% of the variance in cardiovascular control. Rottenberg further noted that confounds in the research literature

were numerous and included medication use, fitness/sedentary lifestyle of the depressed cohort, severity and symptom pattern of the disorder, and sex differences. This author's findings illustrate that although there are relationships between vagal tone and depression, this is not the whole story. In a meta-analysis of the research on self-control and HF HRV, Zahn et al. (2016) found significant but small associations between HF HRV measures at rest and laboratory tasks designed to assess emotion regulation, attentional control, and cognitive control. The authors posited that results of laboratory studies may not fully reflect relations between HF HRV and self-control, as research participants are less motivated to reach peak performance in the laboratory compared to tasks encountered in daily life with high salience.

Tonic positive emotionality has been found to be associated with resting RSA (Oveis et al., 2009). Researchers found significant associations between resting RSA and measures of extraversion (Big Five Inventory), positive mood (the Positive and Negative Affect Scales), and Trait Optimism (Life Orientation Test). There were no significant relationships found with negative emotionality (i.e. neuroticism, negative mood, trait pessimism). Wang, Lu, and Qin (2013) replicated a portion of Oveis et al.'s work; using the PANAS as a measure of trait positive affect, researchers found a positive association between positive emotional style on repeated administration of the PANAS and baseline RSA.

Carver and White's Behavioural Inhibition Scale and Behavioural Activation Scale (BIS-BAS) are a commonly used measure of motivational systems theorized to explain behaviour and affect (1994). BAS is associated with behaviour motivated by reward (i.e. maximize reward through approach or active avoidance); BIS is associated

with behaviour motivated by punishment (i.e. avoidance of negative outcome, anxiety). Brenner, Beauchaine, and Sylvers (2005) attempted to use physiological measures to index BIS and BAS activation in 50 undergraduates undergoing a reward and extinction task. RSA and pre-ejection period (PEP; the time between left ventricular depolarization and ejection of blood from the heart to the aorta) were posited as measures of approach motivation or BAS activation; RSA was used as a measure of PNS activation, while PEP was used as a measure of sympathetic nervous system (SNS) activation. Electro-dermal responding (EDR) was proposed as a measure of BIS activation. However, participant's BIS-BAS questionnaire scores correlated more highly with affective measures on the PANAS than with RSA, PEP, or EDR responding. Self-report measures revealed a relationship between the BIS scale and negative affect as measured by the PANAS, and 3 of 4 BAS scales were related to measures of positive affect on the PANAS. RSA responsiveness was significantly correlated with the Reward Responsiveness subscale of the BAS in the extinction condition. This study provides evidence that although self-report measures and psychophysiological measures may be related in theory, in practice these do not measure precisely the same constructs, and as such caution is appropriate when interpreting results.

These studies give evidence that HF HRV is a useful index of state and trait measures of affect, consistent with the conception of high HF HRV as an indicator of an adaptive emotional style.

Sleep Deprivation, Heart Rate Variability, Performance and Affect

In a study of cognitive performance in Chronic Fatigue Syndrome (CFS), CFS sufferers and matched controls completed tests selected to evaluate sustained attention, working memory and response flexibility (Beaumont et al., 2012). The authors found an association between low cardiac vagal tone and cognitive impairment in CFS, characterized by slower performance, lower HRV, greater heart rate reactivity and prolonged heart rate recovery to cognitive challenge. It was noted that subjective ratings of fatigue and mood did not predict the outcomes of the cognitive testing. In a study of 79 healthy undergraduate men, researchers examined relationships between habitual sleep times (assessed with actigraphy) and cardiovascular response during stressors (i.e., a Stroop task and multisource interference task); Shorter sleep times were related to greater reductions in HF HRV during cognitive tasks utilized as stressors (Mezick, Matthews, Hall, Richard Jennings, & Kamarck, 2014). The greater reduction in HF HRV among short-sleepers was interpreted as greater parasympathetic nervous system withdrawal in response to the task demands.

During a 40-hour sleep deprivation study, Chua and colleagues (2012) found that HRV (in the low frequency range) was comparable to EEG delta power in predicting response lapses on a Psychomotor Vigilance Test (PVT, i.e. a simple reaction time task); EEG delta power has been shown to be a reliable predictor of attentional impairment during sleep deprivation. It is noteworthy that HRV between 0.02-0.08 Hz was the range found to be associated with psychomotor vigilance, as this is outside of the more commonly referenced HF or RSA band of HRV (0.12-0.40 Hz or 0.15-0.40 Hz) that has been the focus of the present review. The origins of HF HRV have been shown to be

driven by the parasympathetic branch of the nervous system as discussed previously; LF HRV has been shown to be a product of both parasympathetic and sympathetic nervous system activity and it is thus difficult to interpret the meaning of group differences in LF HRV (Reyes del Paso, Langewitz, Mulder, van Roon, & Duschek, 2013).

In a retrospective study, Chua et al. (2014) defined a subset of participants from a 26-hour sleep deprivation study as vulnerable or resilient to sleep deprivation based on PVT lapses (RT > 500ms) in the top or bottom third of scores obtained during the study. Vulnerable (n = 15) and resilient (n = 15) participants did not differ on subjective ratings of sleepiness and no group differences were identified in recovery sleep. Vulnerable participants demonstrated more variable and slower response times on the PVT at baseline (i.e. more behavioural impairment) and the researchers speculated that baseline differences were magnified by the sleep deprivation manipulation, resulting in trait-like individual vulnerability to sleep loss. Vulnerable participants had higher HRV power in the low frequency (LF, 0.04-0.15 Hz) band measured during PVT testing at intervals throughout the sleep deprivation day (i.e. at 4 hours awake and every 2 hours until 24 hours awake). HF HRV (0.15-0.40 Hz) power was elevated for vulnerable participants between 16 and 24 hours awake, which would be the usual hours for sleep; suggesting that attention allocation during the PVT task was different for the vulnerable and resilient groups. This study provides support for the calculation of a HF HRV reactivity score between a baseline recording and task performance as a useful measure to explore the possible role of HF HRV as a trait-like measure of vulnerability to sleep loss in the present thesis.

Hall et al. (2004) examined overnight HRV measures in a sample of 59 heathy undergraduate students. Just prior to sleep onset during a night in the lab where polysomnography was recorded, the experimental group was told they would be presenting a 15-minute speech in the morning that would be evaluated, while a control group was told they would be asked to read a magazine in the morning while electrophysiology recordings were made. Examination of HF HRV over the course of the night revealed a pattern of increased HF HRV in the control group in all sleep stages compared to the experimental group. This was interpreted by the authors to indicate that the acute stressor was related to decreased activity of the PNS during sleep. Brosschot, Van Dijk, and Thayer (2007) expanded on those findings with a study examining daily worry and stressful events in 52 volunteers (aged 15-65); participants completed baseline measures of trait anxiety and trait worry, wore mobile physiology recording devices, and completed hourly diary entries as they carried out their normal daily routine. Psychophysiological recordings were continued during the subsequent night of sleep at home and devices were returned to the laboratory the following morning. Diary entries were composed of the occurrence of stressors as well as number and duration of episodes of worry. Stressors and worry were related to increased heart rate, and lower HRV during both wake and nighttime sleep; trait anxiety and trait worry were related to increased heart rate and lower HRV during wake. The authors proposed a model wherein worry duration acted as a moderator of the effect of daily stressors on heart rate and HRV, after controlling for age, gender, and lifestyle factors.

This evidence suggests that HRV could serve as a useful predictor of vulnerability to sleep loss in terms of attentional regulation and cognitive processes involved in the

processing of emotional material. Stress induction paradigms, as described above, suggest that daytime stress impacts cardiac function during both wake and subsequent nighttime sleep. HF HRV may serve as a moderator which could account for differences in the magnitude of individual responses to sleep loss.

Aims of the Current Study

The literature reviewed here supports impairment of self-regulatory control of attentional and affective processing systems with sleep loss, aspects of which can be examined through behavioural and psychophysiological measures acquired during task performance and at baseline (Banks & Dinges, 2011; Chua et al., 2014). It remains unclear, however, what conditions result in sleep deprivation leading to emotional blunting versus enhanced responsiveness to stimuli. Recent research has demonstrated enhanced emotional response to negative events and an absence of elevated mood in response to positive events in medical residents working a night shift in a busy hospital setting (Zohar et al., 2005); blunted ERP response to sad faces yet enhanced processing of angry and fearful faces (Cote et al., 2014); blunted subjective ratings of the emotional expression conveyed by happy and angry faces (van der Helm et al., 2010); blunted facial expressiveness in response to amusing and sad film clips (Minkel, Htaik, Banks, & Dinges, 2011); reduced aggressive responding to provocation during a computer game that was associated with reductions in testosterone in sleep deprived males (Cote et al., 2013); enhanced impulsivity shown by failure to inhibit responses to negative emotional words (Anderson & Platten, 2011); enhanced reactivity quantified by fMRI in response to positive versus neutral pictures (Gujar et al., 2011); enhanced reactivity quantified by fMRI in response to negative versus neutral pictures (Yoo et al., 2007); increased LPP

ERP responses to emotional (negative and positive) pictures versus neutral pictures (Cote et al., 2015); as well as enhanced peripheral nervous system pupillary reactivity to negative versus neutral and positive pictures (Franzen et al., 2009).

As well, evidence suggests individual subjective reports of fatigue and emotional state are inconsistent with behavioural and psychophysiological outcome measures (Banks & Dinges, 2011). Therefore, despite a body of literature on subjective mood states related to sleep deprivation (Koslowsky & Babkoff, 1992; Pilcher & Huffcutt, 1996), further research making use of behavioural and psychophysiological measures of cognitive processing, autonomic arousal, attention, and affective state are needed for a fuller understanding of the mechanisms underlying sleep loss-related alterations in emotion processing and behaviour.

In previous research from the Brock University Sleep Research Laboratory, one night of sleep deprivation was shown to impact neural responses to emotional faces (Cote et al., 2014) and emotional pictures (Cote et al., 2015). In order to extend those findings, the current study investigated a single night of sleep restricted to four hours in order to study a degree of sleep loss that is more naturalistic and commonly experienced.

The focus of the current study was to investigate the role of HRV in predicting vulnerability to one night of sleep restriction. Based on the research reviewed here, the following expected outcomes and hypotheses were made:

1. One night of sleep restricted to 4 hours (03:00-07:00) would be sufficient to impact alertness and subjective mood states.

2. Sleep restriction would be associated with alterations in performance to emotional processing tasks in terms of behavioural and neural outcome measures. Based on previous research with ERP responses to emotional picture viewing, it was expected that performance would be impacted to a greater degree to stimuli with negative valence and that responses to sad face stimuli would be distinct from responses to threat-relevant face stimuli (Cote et al., 2014; Cote et al., 2015). It was also predicted that behavioural responding to emotion processing tasks would be affected by sleep loss and that high relative HF HRV would be associated with higher accuracy and faster RT to tasks overall, in line with research associating higher HF HRV to more effective emotion regulation and to improved performance to tasks associated with executive function (Beauchaine, 2015; Hansen, Johnsen, & Thayer, 2003). It was also predicted that high HF HRV would be associated with better performance at identification of emotion in facial expressions when the emotion was displayed at subtle levels of intensity, as previous research demonstrated relations between higher HF HRV and more accurate recognition of emotional expressions on the Reading the Mind in the Eyes (RMET) task (Quintana et al., 2012).
3. It was hypothesized that HF HRV at baseline (during orientation) and on the experimental day (6-8 days after orientation) would be stable for participants in the rested control condition, and that HF HRV at baseline would be related to measures of affective style. HF HRV has been shown in previous research to be a trait-like measure associated with individual differences in personality and

affective style (Thayer & Lane, 2000) that is stable over time (Kleiger et al., 1991; Pitzalis et al., 1996).

4. It was hypothesized that HF HRV reactivity (i.e. change between baseline and task) would be greater for the sleep restriction group compared to the control group. Research has shown that reductions in HF HRV were greater during task performance for habitually short sleepers compared to normal sleepers (Mezick et al., 2014), and psychological challenge or mental stress has been shown to reliably produce vagal withdrawal, indexed by a reduction in HF HRV (Cacioppo et al., 1994; Houtveen, Rietveld, & de Geus, 2002).
5. As a stable within-subject variable that is sensitive to the effects of sleep deprivation, the primary focus of the thesis was to examine HF HRV as a predictor of vulnerability to performance deficits on emotion processing tasks. Research has related low baseline HF HRV to impaired top-down processing (pre-frontal functioning), resulting in increased dependence on bottom-up processing (Park & Thayer, 2014). Research has also shown that sleep deprivation reduces connectivity between the amygdala and pre-frontal cortical regions during emotional picture processing tasks (Gujar et al., 2011; Yoo et al., 2007). HF HRV may therefore be useful in predicting individual differences in vulnerability to sleep loss and resultant alterations in how emotional material is processed. Based on the relationships between HRV, sleep deprivation and pre-frontal cortical functioning, it was hypothesized that baseline HF HRV and HF HRV reactivity (change between baseline and task) would predict vulnerability to sleep loss, through accounting for variability in the degree of impairment on emotion

processing tasks as quantified by behavioural (e.g., RT) and electrophysiological (e.g., N170 ERP to faces, LPP ERP to pictures) performance indicators.

Method

Participants

Participants were recruited for participation in a study on the effects of sleep deprivation on attention and emotion. Recruitment was carried out via the Psychology Department's online recruitment system, classroom presentations, and posters. Recruitment began in June 2013 and was completed in November 2015. Eligibility criteria to ensure a sample composed of healthy, good sleepers included: age 17-30, non-smoker, and no history of sleep disorders, psychiatric diagnoses, head injury, cardiac, or neurological conditions. Participants were right-handed and fluent in English (native speaker or learned before age 8). As well, for the purpose of analysis of hormones (collected for an aggression task not related to the current thesis), women were required to have a regular menstrual cycle; those using hormone contraceptives were not eligible to participate. Participants confirmed they were able to maintain regular nighttime sleep patterns (i.e. sleep approximately 23:00-07:00, not working shift work) for approximately one week during study participation.

A total of 136 participants enrolled in the study; of that number 59 withdrew or were excluded from participation. Individuals excluded due to elevated scores on a mood questionnaire were provided with information regarding on-campus counselling services. During screening, 18 individuals were excluded due to elevated scores on a modified version of the Beck Depression Inventory (the question regarding suicidal feelings was excluded at the request of the Research Ethics Board); 3 participants were excluded due to sleep habits (shifted sleep times) or excessive fatigue; 1 participant was excluded for

concussion injury; 18 participants withdrew or did not respond to communication after completing screening questionnaires. At the Orientation stage, 14 participants withdrew due to loss of interest, illness, or found themselves unable to meet the time commitment for study completion; 2 participants were excluded due to hair styles that precluded application of the electrode cap; 1 participant was excluded due to being diagnosed with a depressive disorder; and, 1 was excluded due to self-reported drug use (daily marijuana use). 1 participant was excluded for non-compliance to study protocol (i.e. sleep times were shifted during the week prior to the main study). A total of 77 participants completed the full study protocol; 3 were excluded from all data analysis due to non-compliance with sleep instructions (i.e. did not adhere to sleep/wake times).

The final sample included 74 participants, 37 in the sleep restriction (SR) group (men: n = 13; M_{age} = 20.49, *SD* = 2.56) and 37 in the rested control group (men: n = 12; M_{age} = 21.03, *SD* = 2.97).

Materials

Screening Questionnaires. A Sleep-Wake Questionnaire was administered in order to assess inclusion criteria such as habitual sleep times, symptoms of sleep disorders (e.g. snoring, excessive daytime napping) as well as familial history of psychiatric, medical, or sleep conditions, and use of medication, stimulants, and cigarette smoking. Additional questionnaires administered included the Epworth Sleepiness Scale (Johns, 1991) and a fatigue questionnaire (Yoshitake, 1978). A modified depression questionnaire was administered in order to screen for depressed mood (BDI; Beck, et al., 1961).

Actigraphy and Sleep and Activity Diaries. Actigraphy monitors (ActiGraph Corp., Pensacola, FL) provided estimates of sleep duration and efficiency. Diaries requested sleep onset, duration, quality and wake time information as well as daytime activity including exercise, caffeine consumption, and any medication taken.

Personality Inventories. Personality traits were assessed with the 50-item IPIP representation of the Goldberg (1992) markers for the big-five factor structure (IPIP-NEO; Goldberg et al., 2006) the Behavioural Inhibition-Activation (BIS-BAS) scales (Carver & White, 1994), the Barratt Impulsivity Scale (BIS-11; Patton, Stanford, & Barratt, 1995), the State Trait Anxiety Inventory – Trait Version (STAI-T; Spielberger, et al., 1983), the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003), the Interpersonal Reactivity Index (IRI; Davis, 1980), and the Buss-Perry Aggression Questionnaire (BPAQ, Buss & Perry, 1992). Chronotype was assessed using the Horne-Ostberg Morningness-Eveningness Scale (Horne & Ostberg, 1976).

Affective State Measures. During the main study day, affective state measures administered included the State-Trait Anxiety Inventory – State Version (STAI-S; Spielberger, et al., 1983), The Positive and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988), the Stanford Sleepiness Scale (SSS; Hoddes, et al., 1973) and visual analog mood scales consisting of four word pairs: calm-irritable, happy-sad, energetic-sluggish, and relaxed-tense. After each emotional processing task, participants were asked to complete a paper version of the NASA Task Load scale as a measure of effort applied to the task (NASA-TLX; Hitt, Kring, Daskarolis, Morris, & Mouloua, 1999).

Electrophysiological Recording. Electrophysiology was recorded using Neuroscan Synamps II amplifiers and V4.5 software (Neuroscan Inc., El Paso). During baseline recording at orientation, a thoracic respiration effort band (Braebon Inc., Ottawa) was used in concert with a three-electrode electrocardiogram (ECG) recording montage (inferior to the right clavicle, lower left ribs, reference inferior to the left clavicle). During recordings on the main study day, ECG (inferior to the left and right clavicle) was recorded in concert with electroencephalography (Neuroscan 64-channel Ag/AgCl Quikcap with a central site reference between Cz and CPz), electromyography (EMG; submental), and electrooculography (EOG: lateral to the eyes and superior and inferior to the left eye). The sampling rate was 1000 Hz, and hardware filters were set at DC to 200 Hz with a 60 Hz notch filter. Impedances were maintained at 10 KΩ or less. Prior to analysis, recordings from the Quikcap were re-referenced offline to the average of the bilateral mastoid sites.

For both orientation and main study day recordings of ECG, participants were seated for a minimum of five minutes prior to acquisition while pen and paper questionnaires were completed. During ECG recording, participants sat quietly watching a "stargazer" screensaver on a computer monitor in a private bedroom. Respiration was not recorded on the main study day due to the electrocap and amplifier configuration that did not allow for addition of a respiration channel in the recording montage; however, it has been shown that it is not necessary to acquire respiration recordings during tasks wherein respiratory drive is not expected to be altered (Denver, Reed, & Porges, 2007; Houtveen et al., 2002). In this study, during both the rested baseline recording and recordings made during computerized tasks, participants remained seated and no verbal

responses were elicited. ECG electrode placement varied slightly between orientation and experimental day recordings; however, both placements allowed for a clear r-wave to be visualized in the ECG record for calculation of inter beat intervals, heart rate, and RSA.

Psychomotor Vigilance Task. A basic reaction time task was presented as part of the Performance Assessment Battery (PAB; Appendix A). Participants were asked to respond by pressing the "zero" key on the keyboard when a 70 dB (1000 Hz, 50 ms) tone sounded. Instructions emphasized the need to balance speed and accuracy during the task. The PVT task is considered a measure of sustained attention, and reliably shows increased variability with reduced vigilance states (Banks & Dinges, 2007). Response time in milliseconds was displayed on the monitor after each trial. A variable inter-trial interval (ITI) was set at 2000-10000 ms, and as many trials as possible were delivered in a 6-minute time frame. Responses were considered invalid if they exceeded 2000 ms or occurred within less than 100 ms of the stimuli.

Emotion Processing Tasks. Participants completed two emotion recognition and rating tasks: an emotional face processing task and an emotional picture processing task. Task stimuli were delivered using E-Prime (Psychology Software Tools, Inc., Pittsburgh). In the first task, participants were shown a face from the Nim Stim Face Stimulus Set (Tottenham et al., 2009). Faces were presented rapidly (400 ms); participants were asked to categorize each face as expressing one of the following emotional expressions: happy, sad, angry, or fearful, using the "D", "F", "J", "K" keys on a standard keyboard (counterbalanced order); or they could choose a neutral response using the space bar. The faces varied in terms of the intensity of the emotional expression, each face being a composite of a neutral face and a fully emotional face from the same model; composite

faces were made using Norrkross MorphX software (Wennerberg, 1997). Faces used in this task were morphed in 10% increments to produce expressions ranging from 20% to 60% of the full emotional face (i.e. a 20% happy expression was produced by combining 80% of the neutral expression with 20% of the full happy expression). Eight models were used with each of the four emotional expressions at five levels of intensity, for a total of 160 pictures. These 160 pictures were presented once in each of four presentation blocks; faces appeared in a pseudo-random order, such that no single model appeared in two consecutive presentations. After the presentation of the face, a blank screen was displayed until a response was selected; once a response was given, an inter-trial interval of 1000-2000 ms began before presentation of the next face. Responses in excess of 6 s after presentation of the stimuli were considered invalid.

In the emotional picture processing task, participants were shown positive, negative and neutral pictures selected from the International Affective Picture Set (Lang, Bradley, & Cuthbert, 2008). Participants were asked to rate each picture on a 5-point scale using the computer keyboard (very positive, slightly positive, neutral, slightly negative, or very negative, using the “D”, “F”, space bar , “J”, or “K” keys on a standard keyboard; response options were counterbalanced). The pictures were displayed until either a response was keyed in or 1500 ms elapsed; if no response was logged within 1500 ms, then a blank screen was displayed until a response was selected. After each response a variable inter-trial interval began lasting 2000-4000 ms prior to the presentation of the next picture. Response times of greater than 10 s were considered invalid. The picture set was comprised of 60 positive, 60 neutral, and 45 negative pictures; the pictures were divided equally across 3 presentation blocks (i.e. 20 positive,

20 negative, and 15 neutral pictures presented in random order within each block). Negative pictures were defined as having valence ratings < 4.0 (valence $M = 2.73$; arousal $M = 5.69$); Neutral pictures had valance ratings of > 4.5 and ≤ 5.0 (valence $M = 4.99$; arousal $M = 2.90$); and, Positive pictures had valence ratings ≥ 7.0 (valence $M = 7.49$; arousal $M = 4.88$). See Appendix B for details of IAPS stimuli used.

Procedures

Study procedures received clearance from the Bioscience Research Ethics Board at Brock University (Appendix C). Upon completion of participation in the study, participants received either a $50.00 honorarium or credit towards an eligible psychology course offered at Brock University. Interested participants were asked to participate in an initial telephone interview in order to conduct a preliminary screening (Appendix D). Participants were then asked to complete a series of online questionnaires to further determine all inclusion criteria were met (i.e. screening for sleep habits, depressive symptoms). Eligible participants were then scheduled to attend a 1-hour orientation in the sleep lab. Due to high rates of attrition at the webform stage, partway through the study the online questionnaires were included as part of the in-lab orientation session; the questionnaires were completed on a computer with a research assistant available to respond to questions. During the in-lab orientation, participants were given a tour of the facility, study procedures were described in detail, and informed consent to participate was obtained (Appendix E). During the orientation session, a baseline (pre-sleep manipulation) heart rate recording was carried out. Participants were then guided through a practice session of the reaction time, emotional face, and emotional picture categorization tasks. In order to monitor compliance to instructions for nighttime sleep,

participants were given an activity monitor to wear and sleep diaries to complete for the week prior to participation in the main study day. On the day prior to their scheduled main study day, participants were contacted via email and informed of their assignment to the control (sleep 23:00-07:00) or sleep restriction (sleep 03:00-07:00) group. Participants were asked to reply to the email to ensure receipt and understanding of instructions.

Both rested control and sleep restriction groups were instructed to awaken at 07:00, eat a normal breakfast and lunch, not to engage in exercise, nap or consume caffeine prior to arriving at the sleep lab at 13:00 to participate in the study. Saliva collection was carried out by participants at home at 22:30 on the night prior to the main study day, and also at 07:00 and 07:30 on the day of the study; participants were provided with pre-labelled test tubes for saliva collection and were instructed to refrigerate samples until the appointment in the sleep lab. Upon arrival in the lab, participants' sleep diaries and activity monitors were checked for compliance and participants were fitted with an electrode cap including bipolar ECG electrodes located below the clavicle. Participants were again seated at a computer in a private bedroom and asked to complete pencil and paper questionnaires for a minimum of 5 minutes, after which a baseline 5 minute ECG recording was obtained. The Performance Assessment Battery (PAB) was then administered, including an Alpha Attenuation Task (AAT), Reaction Time Task (RT), Emotional Face Task, Emotional Picture (IAPS) Task, aggression task, memory task, and a Go/No Go task.

Approximately half-way through data collection, preliminary data analysis was conducted in order to ensure that the single night of sleep restriction was adequate to

impact performance. The outcomes of the preliminary analysis showed group differences on performance measures, supporting the study design of rested control compared to one night of sleep restriction.

Data Analysis

Statistical Assumptions and Outlier Treatment. All data were visually assessed prior to analysis. Normality was assessed though visual examination of Q-Q and P-P Plots, box plots, and further evaluated using measures of skewness and Shapiro-Wilk tests. Non-normal data is noted along with transformations when used in analyses; when data were not normalized via transformations, non-parametric tests were used. In regression and correlation analyses, scatterplots were used to visualize linearity of associations. For all regression analyses standardized residual plots were examined to assess the overall model and homoscedasticity. Independence of residuals was assessed with the Durbin-Watson statistic.

Outliers, multivariate outliers, and possible influential cases were identified through examination of leverage, Cook's Distance, Malhalanobis' Distance, and standardized DFBetas. Outlier treatment is noted in the Results, and excluded cases are noted in footnotes.

For ANOVA analyses, Mauchley's Test of Sphericity was checked; the Greenhouse-Geisser correction was applied where appropriate. Levene's test was used to assess equality of variance between groups for both t-tests and ANOVAs. Pairwise comparisons used a Bonferroni correction in ANOVA follow up tests. Significance

testing was 2-tailed unless otherwise indicated. All statistical analyses were carried out in SPSS, version 22 (IBM Corp., Armonk, NY).

Sleep and Activity Compliance Data. Study participants were asked to obtain regular nighttime sleep (approximately 23:00-07:00 or 24:00-08:00) for the period of one week prior to the experimental night when participants were assigned randomly to a rested control (23:00-07:00) or sleep restriction (03:00-07:00) group. In order to ensure compliance with instructions participants were asked to complete daily Sleep and Activity Diaries (Appendix F) and wear an activity monitor/watch (model GT3X+, ActiGraph Corp., Pensacola, FL). In some cases, fewer than seven nights of data were collected due to scheduling to accommodate for menstrual cycle phase.

Diaries were completed online from home each morning and included information such as sleep and wake times, sleep quality ratings, caffeine and alcohol consumption, and physical activity. The entries were checked daily by a researcher and reminders were sent by email or phone if entries were not completed. Participants were also able to take paper versions of the questionnaire to be returned upon arrival for the main study day. Some diary entries were missing due to technical difficulties (unable to sign into the online portal), unable to access internet, lost paper forms, and forgotten entries (the webform portal allowed only one entry per day and as a consequence missed entries could not be made up via the online system). See Table 1 for number of valid diary entries by night. For participants with completed diaries, participation in exercise was dichotomized as “active” or “sedentary” depending on the presence of any reports of exercise in the diary entries.

Table 1

Number of Sleep and Activity Diary Entries on the Experimental Night (EN) and for Each Night Prior to the EN

	Experimental Night	EN - 1	EN -2	EN - 3	EN - 4	EN - 5	EN - 6
Control	33	33	33	32	32	30	28
SR	33	32	32	31	31	26	25

Note. "EN – 6" signifies number of diary entries logged 6 nights prior to the experimental night

Activity monitors were worn on the left (non-dominant) wrist, and were to be worn continuously with the exception of activities that would cause the unit to be submerged (i.e. shower, swimming, washing dishes) or during contact sports. Data from the activity monitors was downloaded into specialized software upon arrival at the lab for the main study day and analysed for compliance to sleep/wake times (ActiLife V. 6.9.4, ActiGraph Corp., Pensacola, FL). The software computed sleep times and calculated a sleep efficiency score (Appendix G); sleep times were visually verified to be consistent with sleep diary data. Missing activity monitor data occurred due to mechanical failure (battery failure, unit initialization failure), and several instances where the monitor was removed (e.g. for a shower) and then forgotten. See Table 2 for number of valid activity monitor recordings by night.

Table 2

Number of Nights of Activity Monitor / Actigraphy Data Gathered for the Experimental Night (EN) and for Each Night Prior to the EN

	Experimental Night	EN - 1	EN -2	EN - 3	EN - 4	EN - 5	EN - 6
Control	29	29	28	29	27	27	24
SR	30	27	25	28	28	29	28

Note. "EN – 6" signifies number of valid Actigraph recordings logged 6 nights prior to the experimental night

Psychomotor Vigilance Task. Performance on the RT task was examined in terms number of lapses (responses > 500 ms), mean reaction time on correct trials (mean RT correct), the standard deviation of reaction time to correct trials (SD RT Correct), the average of the 10% fastest valid response times (10% fast), and the average of the 10% slowest valid response times (10% slow). The reciprocal of the 10% slow was used for statistical analysis to adjust for skewness.

Emotion Processing Tasks. Raw EEG data was visually assessed and channels with poor signals were removed from the analysis (i.e. channels with 60 Hz noise, electrode pop, et cetera). Eye movement was recorded using vertical and horizontal EOG sensors; eye movement regression algorithms were applied in Neuroscan to the data to correct for eye movement artifact. Stimulus-locked ERPs were epoched from the continuous EEG records between -100 ms and 900 ms for emotional faces and -100 ms to 1200 ms for IAPS pictures. These epochs were baseline corrected and a low pass filter was applied at 30 Hz. Grand average waveforms for each condition (SR and Control) were generated along with counts for valid trials at each stimulus category. Individual waveforms were evaluated and ERP components of interest were manually marked in each file at selected sites. For the Face Task, the N170 component (negative peak occurring at approximately 170 ms after stimulus presentation) was identified where the component was largest at parietal-occipital sites in the right hemisphere (P4, P6, P8, PO4, PO6, and PO8; sites shown in Appendix H). Additionally, the P1 and N250 components were identified in the ERPs, although they were not assessed for the present analysis. For the IAPS emotional picture task, the LPP was identified as a slow positive waveform from 400 to 800 ms at central-parietal sites (Cz and CPz were averaged as a region of

interest and utilized in the present analysis; sites shown in Appendix H). The selected sites were chosen a-priori based on the results of previous research (Cote et al., 2015; Cote et al., 2014).

Cardiac Data. Baseline heart rate recordings were imported into a commercial software package for analysis (MindWare Heart Rate Variability Scoring Module 3.1.0, MindWare Technologies Ltd., Columbus, OH). R-waves were visually checked in the MindWare program, and edited where appropriate according to the recommendations outlined by Berntson and Stowell (1998), who emphasize the importance of identifying both spurious and missed beats in cardiac recordings in order to obtain reliable estimates of cardiac parameters. Spectral analysis of the heart beat series using a fast Fourier Transformation was used to calculate heart rate variability based on 1-minute epochs, which were averaged to determine RSA for each recording. Baseline recordings were 5 minutes in length on both the orientation session and main study day. ECG recordings during task performance were 3 minutes in length and were extracted from a single block of stimulus delivery. ECG was extracted from the second block of stimulus delivery in order to allow sufficient time for blood pressure and HR to normalize when participants returned to a seated position after a brief break between tasks (during breaks they were instructed to walk around the lab in order to maintain alertness). High frequency heart rate variability is defined as the band 0.12-0.40 Hz, and measured values underwent a natural log transformation in order to normalize the resulting distribution. The log transformed HF HRV is hereinafter referred to as RSA. HR and RSA were calculated for orientation baseline ECG (HR_O, RSA_O), main experimental day baseline ECG (HR_M, RSA_M), Face Task ECG (HR_F, RSA_F), and IAPS (emotional picture) Task ECG (HR_I,

RSA_I). Orientation baseline also included respiration calculated in breaths per minute ($Resp_O$). Experimental day and task HR and RSA was used to calculate a task reactivity (i.e. RSA-R_F: task - baseline) score.

Examination of the cardiac data revealed one case with an irregular heart beat; this case was excluded from all cardiac analyses. At the orientation session, one file was lost due to amplifier error. On the main study day, one baseline recording was lost due to excessive artifact obscuring the signal, similarly one file was lost from the Face Task due to artifact, and six files were lost due to artifact during the IAPS Task. More data was lost during the latter task as signal quality deteriorated somewhat throughout the day while participants moved around during breaks between tasks and electrode contacts became less secure.

As the focus on the main hypothesis of the thesis, the details of the data reduction for the cardiac measures were included in detail. Examination of the ECG recording resulted in removal of 1% of the raw ECG data due to the recording being obscured by artifact. 10% of the files analysed were identified as containing brief periods of artifact sufficient to obscure a single r-wave; these cases were corrected by placing the marker for the missing R-wave at the half way point between two identifiable R-waves. See Table 3 for detailed breakdown of missing data by task.

Table 3

Cardiac Data Removed and Treated

	Control			SR		
	n	Removed (%)	MB	n	Removed (%)	MB
Orientation Baseline	36	0.004	1	36	0.003	6
Experimental Day Baseline	35	0.034	4	37	0.011	7
Face Task	35	0.005	2	37	0.009	12
IAPS Task	32	0.047	2	35	0.004	3

Note. MB: "missed beats" were treated via interpolation between 2 identifiable r-waves.

As noted previously, RSA measures were normalized via a natural logarithm transformation. A single outlier was identified for HR-R_F and was removed from analyses including that variable. HR-R_I in the control group was positively skewed (Z_{skew} = 2.77; Shapiro-Wilk p = .004). A median split was used to identify high and low RSA groups within the sample based on the orientation baseline recording (RSA_O).

Statistical Analysis. Pearson correlations were used to assess the stability of HR and RSA at different measurement times, followed by two-way mixed effects model Intraclass Correlation Coefficients (ICC; Shrout & Fleiss, 1979).

The effect of sleep group on dependent variables (i.e. performance on tasks) was evaluated with mixed model ANOVAs, with t-tests or pairwise comparisons to further evaluate group differences. Following ANOVA tests, regression models tested the role of cardiac variables as moderators of the effect of sleep group (SR, C) on outcome measures. Possible covariates were explored in regression analyses, including age, sex, BMI, and exercise participation (Antelmi et al., 2004). Respiration rate from the orientation baseline recording of ECG was included as a possible covariate in analyses incorporating RSA_O. Covariates were entered stepwise into the first step of a regression

model; any covariates that accounted for significant variance in the model were then included in a final regression model while those that did not were discarded. See Appendix I for a diagram of the regression strategy.

Results

Sample Characteristics

The SR and Control groups did not differ on demographic variables (Table 4). No participants identified as strongly morning or evening types on the measure of chronotype (Control: $M = 53.51$, $SD = 7.75$; SR: $M = 47.86$, $SD = 7.17$); the majority of participants identified as neither morning nor evening types (SR = 27; C = 25); however, there were several moderate morning types (SR = 4; C = 9) and moderate evening types (SR = 6; C = 3). There were no group differences for chronotype category, t (72) = 1.72, $p = .09$.

Table 4

Demographic Characteristics of the Sample by Experimental Group

	Control		SR				
	n	M (SD)	n	M (SD)	*t*	*df*	*p*
Age	37	21.03 (2.97)	37	20.49 (2.56)	.84	72	.40
Sex	37	M = 12; F = 25	37	M = 13; F = 24	.24	72	.81
BMI[a]	34	24.07 (4.76)	36	23.64 (4.11)	.41	68	.69
Exercise[b]	36	Active = 19	35	Active = 16	.59	68	.56

Note. [a] BMI was calculated as weight (kg)/(height(m))^2

[b] Exercise was noted in Sleep & Activity Diaries, when exercise was noted in the diaries the participant was classified as "active"

Validation of Sleep Restriction Manipulation

In order to validate that one night of sleep restriction to four hours would lead to decrements in performance, a number of key variables were compared between groups.

Diary and Actigraphy Data. Sleep data from actigraphy monitors and diaries were examined for baseline nights and the experimental night separately. There were no group differences prior to the main study night in sleep duration as measured by actigraphy or self-report in diaries. There were no group differences in the number of

nights of baseline data collected. There was a significant effect of sleep duration on the experimental night, showing that participants complied with instructions to curtail sleep, as summarized in Table 5.

Table 5

Baseline and Experimental Night Sleep Duration and Quality by Experimental Group

	Control			SR					
	n	M (SD)		n	M (SD)		*t*	*df*	*p*
Baseline Nights (Avg)									
TST[a] (hrs/night)									
Diaries	35	7.89	(.64)	34	7.95	(.71)	-.37	67	.71
Actigraphy	31	6.88	(.59)	32	6.75	(.88)	.68	61	.50
SE[b] (%)	31	90.13	(16.16)	32	85.09	(5.97)	1.65	61	.10
Days of Diaries	35	5.37	(1.26)	34	5.21	(1.34)	.53	67	.60
Days of Actigraphy	31	5.29	(1.16)	32	5.16	(1.39)	.41	61	.68
Experimental Night									
TST[a] (hrs)									
Diaries	33	7.63	(.51)	32	3.99	(.25)	36.6	64	<.001*
Actigraphy	29	6.53	(.74)	30	3.67	(.38)	18.7	57	<.001*
SE[b] (%)	29	86.91	(7.12)	30	89.02	(7.14)	-1.14	57	.26

Note. [a] TST is total sleep time in hours.
[b] SE is Sleep Efficiency calculated with actigraphy data (time asleep/time in bed)
* = $p < .05$

Subjective State Data. On the experimental day, SR participants reported more sleepiness on the SSS and less positive affect on the PANAS than control participants. On visual analog scales (VAS) of mood, SR participants endorsed feeling less calm/more irritable, less happy/more sad, less energetic/more sluggish, and less relaxed/more tense than control participants. Subjective measures are summarized in Table 6[1].

[1] Subjective state measures were positively skewed, with the exception of the Positive PANAS scale; consequently, group differences were assessed with a non-parametric test (Mann-Whitney *U* test). There was a single statistical outlier on the initial Calm-Irritable VAS; as removal of the outlier did not impact the pattern of results and appeared to represent an accurate measure of the participant's mood state, the case was left in the analysis.

Table 6

Subjective Mood and Subjective Sleepiness by Experimental Group

	Control		SR			
	n	M (SD)	n	M (SD)	*U*	*p*
STAI-S State Anxiety						
14:00	37	27.08 (6.45)	36	31.42 (6.34)	375.5	.001*
Subjective Sleepiness						
14:00	37	1.89 (0.70)	36	3.42 (1.18)	186.5	<.001*
16:00	37	2.59 (1.17)	37	3.86 (1.25)	298.0	<.001*
VAS Calm-Irritable						
14:00	37	10.62 (13.02)	36	16.67 (12.73)	433.0	.010*
16:00	37	20.76 (20.21)	37	32.14 (20.67)	433.5	.007*
VAS Happy-Sad						
14:00	37	13.38 (12.39)	36	24.42 (18.33)	429.0	.009*
16:00	37	20.95 (14.63)	37	34.46 (18.69)	403.5	.002*
VAS Energetic-Sluggish						
14:00	37	27.05 (20.74)	36	57.81 (22.24)	216.5	<.001*
16:00	37	40.65 (24.73)	37	62.97 (23.57)	355.5	<.001*
VAS Relaxed-Tense						
14:00	37	12.27 (12.52)	36	22.33 (15.85)	388.0	.002*
16:00	37	20.11 (18.73)	37	32.84 (20.92)	419.5	.004*
PANAS-Positive						
14:00	37	34.19 (7.15)	34	26.94 (8.76)	317.5	<.001*
16:00	37	29.57 (8.73)	36	22.64 (7.53)	380.0	.002*
PANAS-Negative						
14:00	37	11.46 (1.92)	34	11.74 (2.09)	581.5	.571
16:00	37	12.11 (2.13)	36	12.50 (3.31)	652.5	.878

Note. Subjective state measure was administered at 14:00 at the onset of the PAB and repeated at 16:00 after completion of both the Face Task and IAPS Task.
* = $p < .05$, † = $p < .10$

Psychomotor Vigilance Task Data. SR participants demonstrated slower and more variable RT on the PVT as shown by mean values in Table 7. The slowest 10% of responses were significantly slower for SR than Control participants[2]. 10% slow is calculated as the average of the 10% slowest response times on the PVT; this variable is of interest as a measure of the most impacted responses on the task. Sleep loss has been

[2] One case was identified as an outlier 10% slow, SD RT Correct, and lapses and was excluded from the PVT analysis (AG85). All RT measures were positively skewed. The distribution of the 10% slow responses normalized via an inverse transformation, while mean RT, SD RT and 10% fast were normalized with a log 10 transformation

shown to impact performance in a variable manner due to moment to moment changes in alertness (Killgore, 2010).

Table 7

Reaction Time on the Psychomotor Vigilance Task

	Control		SR				
	n	M (SD)	n	M (SD)	*t*	*df*	*p*
Mean RT Correct (ms)	36	252.81 (34.14)	36	266.17 (32.18)	-1.8	70	.075†
Standard Deviation RT	36	41.54 (18.42)	36	57.46 (28.0)	-3.0	70	.004*
10% Fast (ms)	36	204.50 (25.37)	36	208.23 (21.09)	-.78	70	.44
10% Slow (ms)	36	338.69 (68.41)	36	387.01 (78.32)	2.9	70	.005*

Note. M and SD are raw values, t-tests were conducted on transformed data (Mean RT, SD RT, 10% Fast underwent Log 10 transformation; 10% Slow underwent an inverse transformation).
* = $p < .05$, † = $p < .10$

In summary, SR participants reported decreased positive mood, increased subjective sleepiness, and demonstrated slower and more variable RT on the PVT relative to control participants. These measures confirm that a single night of sleep restricted to four hours was sufficient to impact mood and performance as predicted.

Effects of Sleep Restriction on Emotional Processing

Face Task. On the Emotional Face Task, participants were able to identify facial expressions by Emotion Type (happy, sad, fearful, or angry) more reliably at higher Intensity of expression (Figure 1).

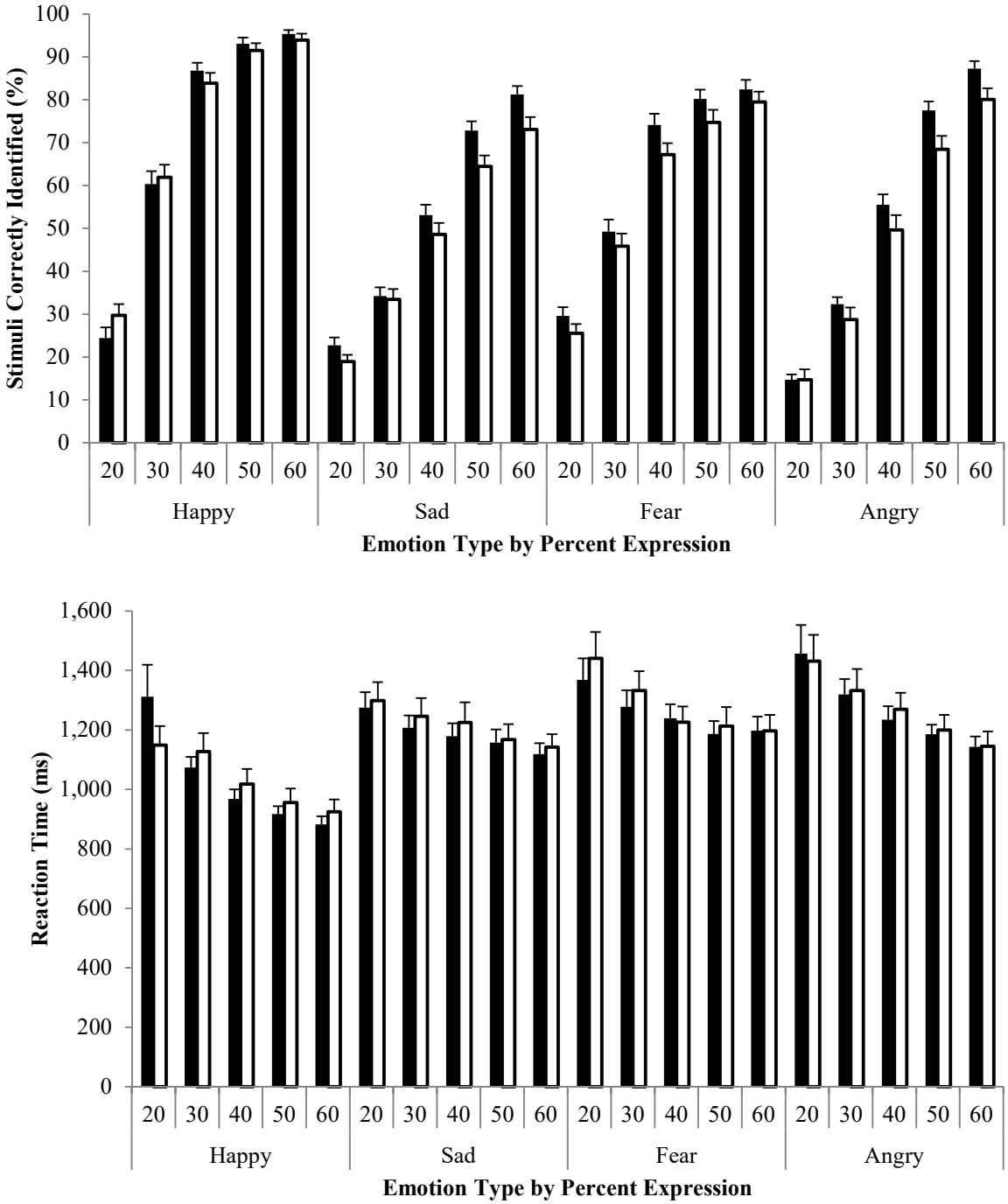

Figure 1. Accuracy and Reaction Time to Emotional Face Task for All Stimuli: Control (solid bars) and SR (open bars).

Participants showed increased accuracy for identification of Emotion Type and faster RT as the Intensity of emotional expression increased (60% expression is a composite that is 60% of an actor's full emotional expression combined with 40% of their neutral expression). Error bars represent Standard Error.

Performance on the Face Task was assessed though a measure of threshold sensitivity (degree of expression necessary for identification of emotion in the face), and accuracy (ability to correctly identify the emotional expression shown in the face).

Threshold sensitivity. Performance on the Face Task was first evaluated in terms of the intensity of expression at which each participant reliably perceived emotion in the stimuli. Threshold sensitivity was calculated using the full range of face stimuli by evaluating the percentage of stimuli identified as emotional (i.e., non-neutral responses), and establishing the intensity of expression present where the participant perceived emotion on at least 75% of trials for each emotion. Threshold sensitivity was similar for Happy (SR: $M = 37.22$, $SD = 9.14$; C: $M = 36.57$, $SD = 5.91$) and Fearful faces (SR: $M = 36.11$, $SD = 7.28$; C: $M = 37.14$, $SD = 5.19$), and higher for Sad (SR: $M = 47.50$, $SD = 10.79$; C: $M = 46.57$, $SD = 6.39$) and Angry (SR: $M = 48.06$, $SD = 9.51$; C: $M = 46.57$, $SD = 5.91$). A mixed model ANOVA was conducted for Group (C, SR) by Emotion Type for Threshold Sensitivity; A main effect for Emotion Type was present, $F(3, 204) = 68.72$, $p < .001$, $\eta^2 = .50$; pairwise comparisons confirmed that participants were able to identify Happy and Fearful faces at more subtle levels of expression than Sad and Angry faces (p's $< .001$). There was no main effect for Group or interaction between Group and Emotion Type (Appendix J).

Accuracy. Examination of behavioural performance on the Face Task illustrated that accuracy was low to the 20 and 30% face stimuli (Figure 1), and suggests that the emotional expressions were below threshold for identification of emotion in the faces. Thus, further analysis of performance on the Face Task focussed on the 40-60% face

stimuli. For the purpose of analysis, composite scores for Accuracy and RT to the 40, 50, and 60% Intensity stimuli were calculated.

A Group (C, SR) by Emotion Type (happy, sad, fearful, angry) mixed model ANOVA was conducted for Accuracy (identifying the correct emotional expression displayed in the 40-60% Intensity stimuli)[3]. Tests of between subject effects confirmed that SR participants were less accurate than control participants at identifying Emotion Type, F (1, 69) = 4.97, p = .029, η^2 = .07. There was a significant main effect of Emotion Type, F (3, 207) = 88.28, p < .001, η^2 = .56; pairwise comparisons showed significant differences between all four Emotion Types (all p's ≤ .04), accuracy was highest to Happy, followed by Fearful, Angry, and lowest to Sad. There was no significant interaction for Emotion Type by Group (Figure 2)[4]. These results indicate that SR participants were less sensitive to facial cues for different emotions than rested controls.

[3] Exclusions: KE64, VS51, AG85, and KH102.
[4] A Group (SR, C) by Negative Emotion (sad, fearful, angry) mixed model ANOVA was non-significant for Accuracy on the Face Task.

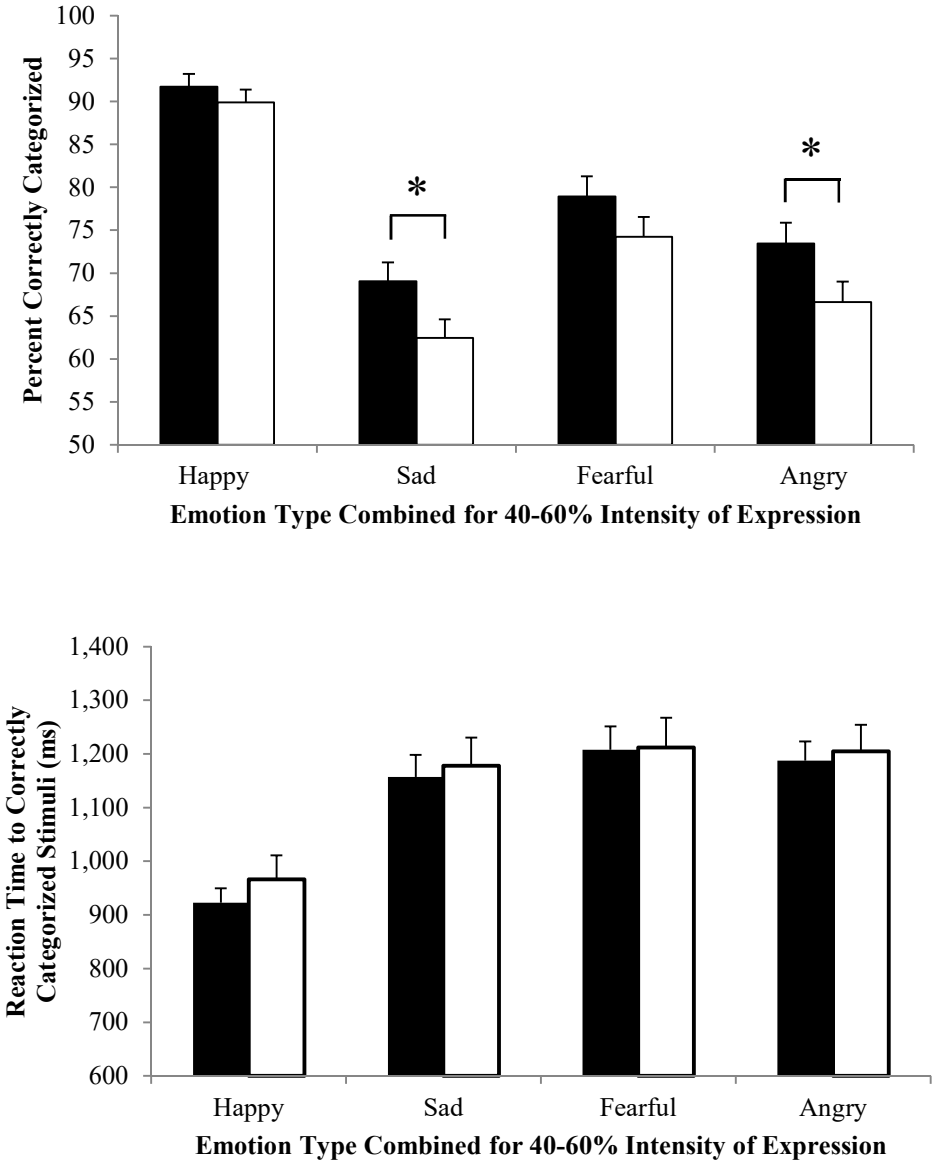

Figure 2. Accuracy (percent of stimuli correctly categorized) and Reaction Time (to correct trials) by Emotion Type (combined for 40-60% Intensity stimuli). SR participants were less accurate and slower on the Emotional Face Task. * = significant group differences at $p < .05$.
Controls = solid bars; SR = open bars. Error bars represent Standard Error.

Because of the a priori hypotheses and prior research showing group differences depending on Face Type, and the overcorrection for multiple comparisons inherent in the Group by Face Type ANOVA, t-tests were conducted on the Accuracy scores for Emotion Types. T-tests indicated that SR participants, compared to rested controls, were less accurate at identification of Sad and Angry faces (Table 8).

Table 8

Group Differences in Accuracy for Identification of Emotional Face Type

	Control		SR				
	n	M (SD)	n	M (SD)	*t*	*df*	*p*
Happy	35	91.73 (7.41)	36	89.90 (9.95)	0.87	69	.385
Sad		69.05 (11.52)		62.45 (14.25)	2.14	69	.036*
Fear		78.92 (12.85)		74.24 (14.84)	1.42	69	.160
Angry		73.44 (10.89)		66.61 (17.03)	2.00	69	.049*

Note. Accuracy to Face stimuli at the 40, 50, & 60% Intensity of expression combined.
* = $p < .05$

Reaction Time. Reaction Time[5] was calculated for correct responses to 40 to 60% Intensity stimuli combined (Figure 2). A Group (SR, C) by Emotion Type (happy, sad, fearful, angry) mixed model ANOVA was conducted for RT. RT varied by Emotion Type, F (3, 207) = 82.86, p <.001, η^2 = .55; pairwise comparisons indicated that RT was faster to happy compared to all other emotions (all *p's* < .001). Although RT was slower in the SR group, the ANOVA did not show a significant main effect of Group. There was no Group by Emotion Type interaction[6].

Event-Related Potentials. ERP analyses used a composite of neural responses to stimuli at the 40, 50, and 60% Intensity of emotional expression for each Emotion Type; Grand average waveforms by group are displayed in Figure 3.

[5] RT was positively skewed for all stimuli types; the RT scores were normalized via a square root transformation.
[6] A Group (SR, C) by Negative Emotion (sad, fearful, angry) mixed model ANOVA was non-significant for RT on the Face Task.

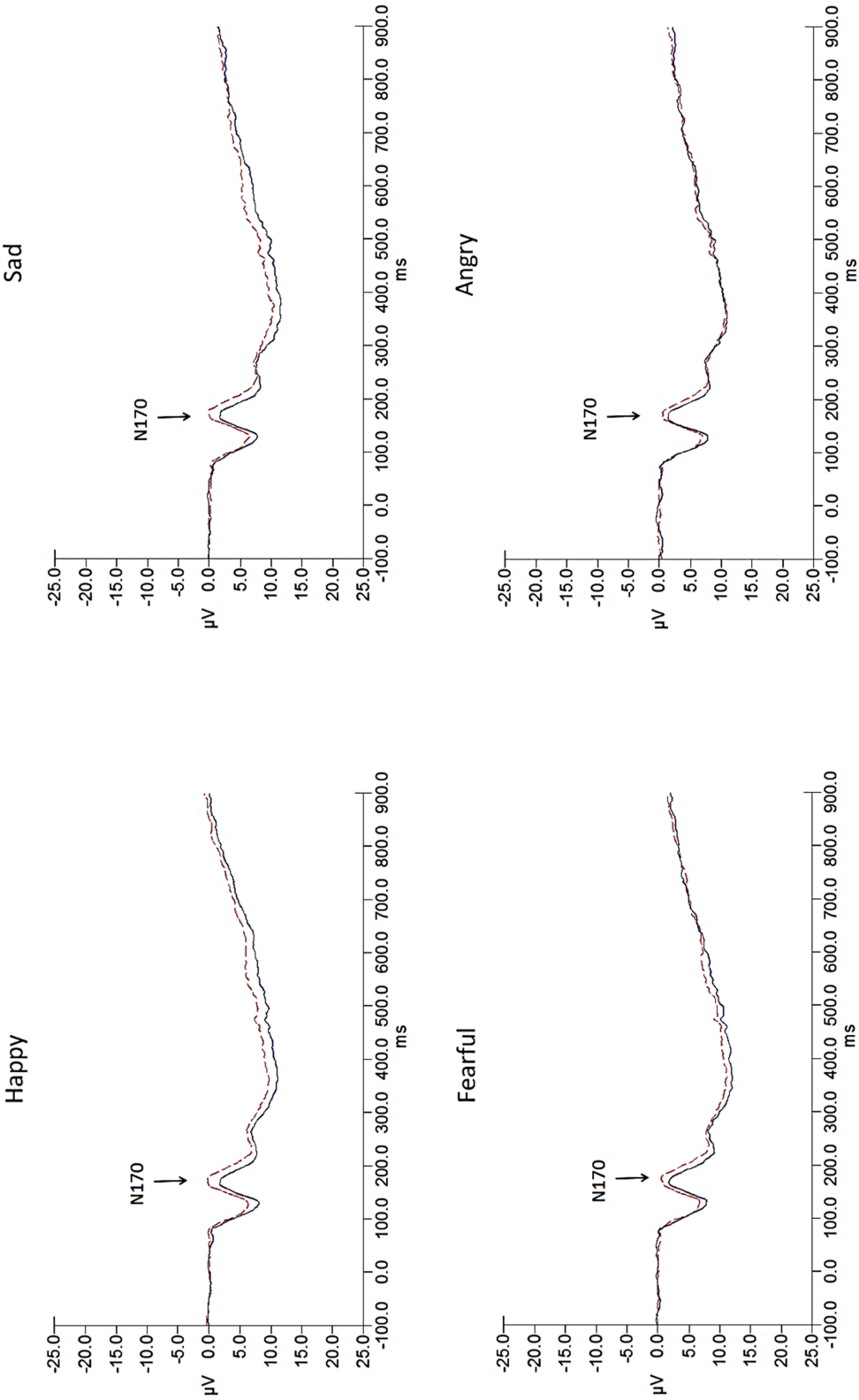

Figure 3. N170 ERP grand averages for each emotional face category by sleep condition at PO8. SR group (broken line) shows a more negative N170 to emotional faces than the rested Control group (solid line).

The N170 component of the ERP response was measured (amplitude in uV) to each Emotional Face Type (happy, sad, fear, angry) for each participant[7]. Inclusion of responses to 40-60% Intensity stimuli allowed a maximal number of valid trials to be included in the analysis (see Appendix K for number of trials included in the ERPs and latency of the N170). The N170 was identified at the following parietal-occipital sites: P4, P6, P8, PO4, PO6, and PO8, and was maximal at PO8.

A Group (SR, C) by Emotion Type (happy, sad, fearful, angry) mixed model ANOVA yielded a significant interaction for N170 amplitude at PO8, F (3, 180) = 3.46, p = .018, η^2 = .055[8]. Means and Standard Deviations are reported in Table 9. Follow up t-tests indicated trends toward Group differences in N170 amplitude to Happy faces, t (61) = 1.92, p = .061, and Sad faces, t (61) = 1.95, p = .056. No group differences were found for Fearful, t (62) = 1.48, p = .14 or Angry faces t (62) = .75, p = .46. To clarify the interaction between Group and Emotion, and in line with previous research, t-tests were conducted within Groups by Emotion Type (happy, sad, fearful, and angry). In the Control group, the N170 was larger to Angry compared to Fearful faces, t (31) = 2.05, p = .049; in the SR group, the N170 to Sad faces was larger than that to Fearful, t (30) = -2.88, p = .007 or Angry faces, t (30) = -2.49, p = .018, and the N170 to Happy faces was larger than that to Fearful, t (30) = -2.21, p = .035 (Figure 4).

[7] Excluded from Face Task ERP analysis: DG31, KE64, KK58, RR84, VS51, AS47, KB67, KH102, SW95, and UH117; BB118 excluded from Sad; and, YS13 excluded from Happy.

[8] Levene's Test indicated variances were unequal between Groups on N170 to Happy (p = .04) and Sad (p =.03). A Group (SR, C) by negative Emotion (sad, fearful, angry) repeated measures ANOVA showed a significant interaction effect of group by emotion for N170 amplitude F (2, 122) = 4.62, p = .012, η^2 = .07.

Table 9

N170 Amplitude at PO8 by Emotional Face Type

	Control		SR	
	n	M (SD)	n	M (SD)
Happy	32	0.69 (4.24)	30	-1.48 (5.84)
Sad		0.57 (4.39)		-2.11 (6.06)
Fearful		0.79 (4.10)		-0.84 (5.87)
Angry		-0.19 (4.51)		-0.99 (5.84)

Note. Lower (more negative) means represent larger N170 components.

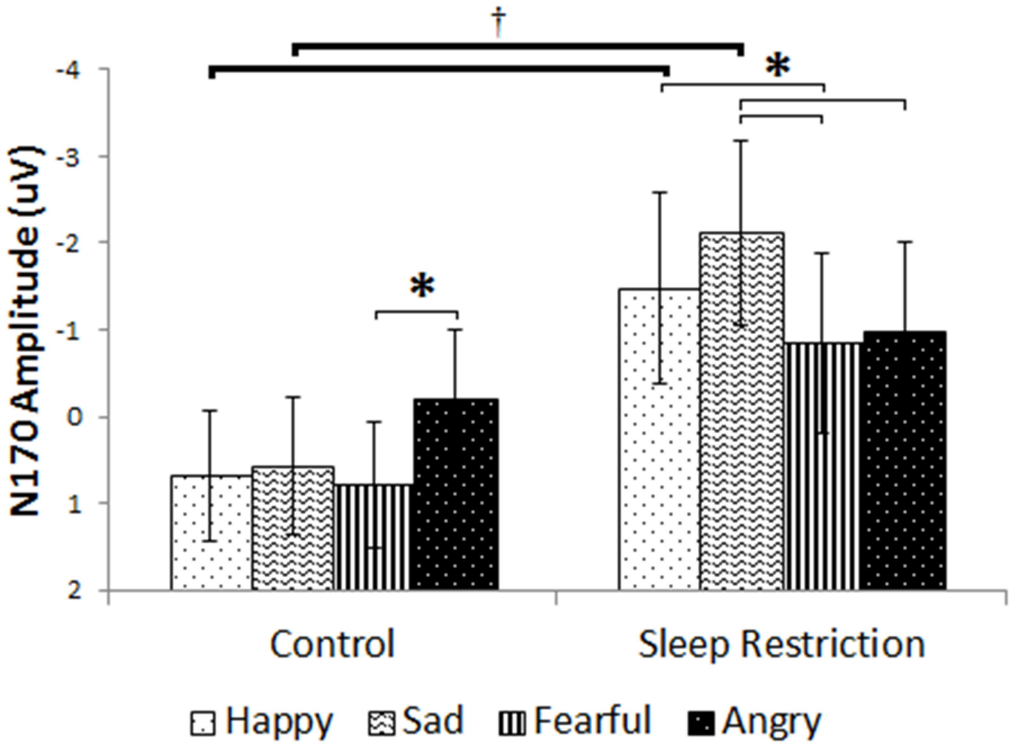

Figure 4. Mean N170 amplitude at PO8 to emotional expressions, showing a trend for a larger (more negative) N170 in SR compared to Control to Happy and Sad faces.
In the Control group, the N170 was larger to Angry compared to Fearful faces; In the SR group the N170 was larger to Sad faces compared to either Fearful or Angry faces, and N170 to Happy faces was larger than to Fearful faces.
* (thin line) = $p < .05$, † (heavy line) = $p = .06$, error bars represent Standard Error.

In summary, on the Emotional Face Task, SR was associated with reduced accuracy in identification of Sad and Angry facial expressions. There was an interacation between Group and Emotion Type for neural response to Faces: SR participants showed a tendency for larger N170 response to Happy and Sad faces. Further evaluation of the interaction revealed different patterns of responding by Emotion Type within experimental groups: Controls had a larger N170 to Angry faces compared to Fearful faces; SR had a larger N170 to Sad faces relative to both Fearful and Angry faces, and a larger N170 to Happy faces relative to Fearful faces. The interaction between Group and Emotion Type for N170 response to the Face Task seems best understood in terms of responses to Happy and Sad face stimuli specifically, with similar repsonses to threat-related faces (Fearful, Angry) between the SR and Control groups.

IAPS Task. Performance on the IAPS Task was assessed in terms of Accuracy and RT to the instruction to categorize each picture as negative, neutral or positive[9]. Group (SR, C) by Emotion Type (negative, neutral, positive) mixed model ANOVAs revealed no interactions between Group and Emotion Type for Accuracy or RT to the IAPS Task. As shown in Figure 5, performance appeared to reach a ceiling effect as both groups demonstrated high accuracy. There was an effect of Emotion Type on Accuracy, F (1.46, 102.06) = 6.48, p = .006, η^2 = .08. Pairwise comparisons confirmed that accuracy was significantly higher for Negative pictures relative to Neutral (p < .001) and for Negative relative to Positive (p = .005). Tests of between-subjects effects showed a trend for lower accuracy in SR, F (1, 70) = 3.83, p = .054, η^2 = .05.

[9] Excluded from IAPS Emotional Picture Task analyses were CB16 and AG85.

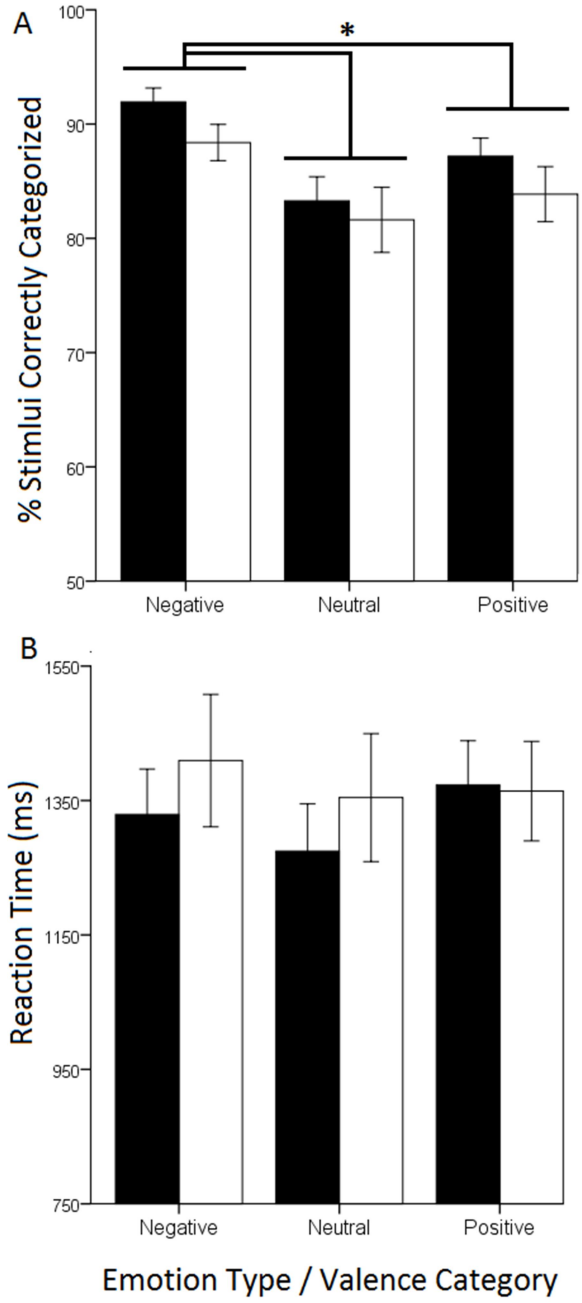

Figure 5. A: Accuracy shown in terms of percent of stimuli correctly classified as Negative, Neutral or Positive by Group. Negative stimuli were identified with more precision than either neutral or positive; * indicates significant differences by Emotion Type.
B: Reaction Time for each Emotion Type for correct responses by Group.
Control group = solid bars; SR group = open bars. Error Bars represent Standard Error.

Event-Related Potentials. The Late Positive Potential (LPP) ERP component was selected as a variable of interest in the IAPS Emotional Picture Task; Figure 6 depicts grand average ERP waveforms to Negative, Neutral, and Positive IAPS pictures (see Appendix K for the number of trials included in ERPs). The LPP was measured at central-parietal sites in the 400-800 ms window after stimulus onset; a region of interest was examined at Cz and CPz.

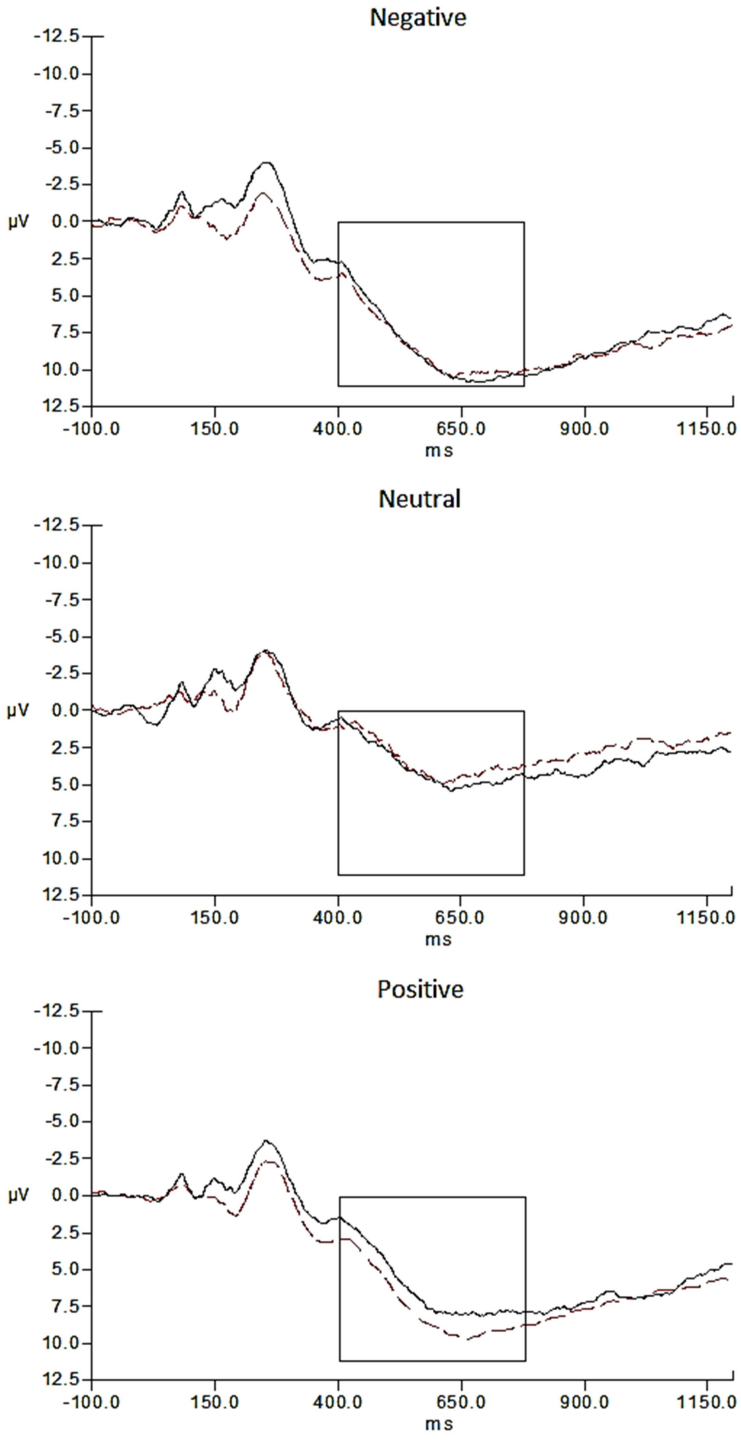

Figure 6. LPP at Cz and CPz to Negative, Neutral, and Positive IAPS pictures, by group; the LPP was measured from 400-800 ms after stimulus onset (marked by boxes). SR = broken line; C = solid line.

A Group (SR, C) by Emotion (Negative, Neutral, Positive) mixed model ANOVA revealed interactions for LPP to emotional pictures at several sites, including the region of interest comprised of Cz and CPz: F (2, 138) = 3.13, p = .047, η^2 = .04 (Figure 7a). The interaction was also significant at the following sites: CPz, C1, C4, and P2 (all p's < .05); there were trends at Cz, C2, and CP2 (all p's <.08). There was an effect of Emotion on LPP amplitude at Cz and CPz, F (2, 138) = 58.81, p < .001, η^2 = .46. Pairwise comparisons showed that the LPP to Neutral was less than that to Positive, which was less than that to Negative (all p's ≤ .005).

As a follow up to clarify the nature of the Group by Emotion interaction, difference scores were calculated to quantify the change in LPP amplitude to Positive – Neutral stimuli and Negative – Neutral stimuli (see Figure 7b). T-tests confirmed significant Group differences for Positive – Neutral, t (69) = -2.27, p = .026, but not for Negative – Neutral, t (69) = -.78, p =.44). Emotional processing was impacted by sleep restriction in terms of altered (enhanced) response to positive stimuli relative to neutral stimuli, in the SR group as indexed by the LPP to picture stimuli.

In summary, emotional processing was impacted by a single night of sleep restriction in terms of behavioural and neural response to an emotional face processing task, as well as to an emotional picture viewing task. These overall group effects provide insight into the manner by which sleep loss impacts affect and behaviour; however, it is necessary to consider individual differences in vulnerability to sleep loss through examination of psychophysiological measures (RSA) and measures of personality and affective style.

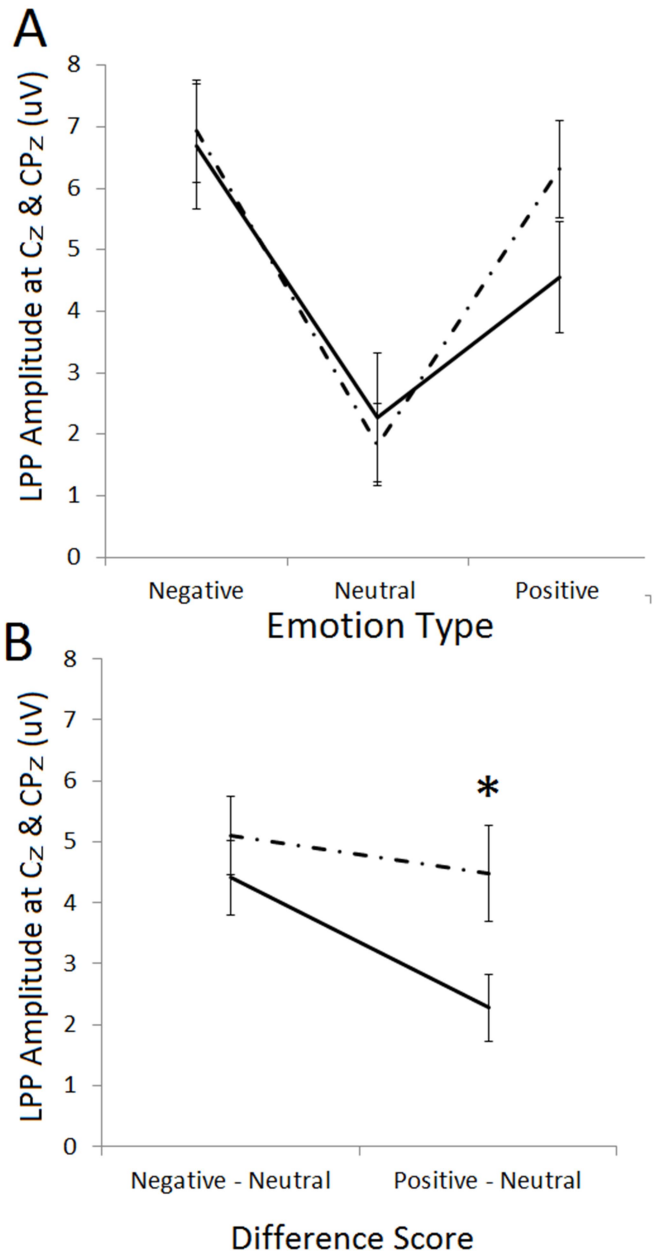

Figure 7. A: LPP amplitude at the average of Cz and CPz (400-800ms) to emotional pictures from the IAPS Picture Set; Controls showed the expected pattern of larger LPP to emotional vs. neutral and larger LPP to negative vs. positive emotional valence.
B: Difference (Emotional – Neutral) scores clarify the Group by Emotion interaction; the SR group showed a larger LPP to Positive relative to Neutral compared to controls, showing increased processing of Positive stimuli in the SR group.
SR group = broken line; Control group = solid line; * = significant difference; Error bars represent Standard Error.

Effects of Sleep Restriction on Cardiac Measures

Intraclass Correlation Coefficients, shown in Table 10, were calculated in order to confirm stability of cardiac measures between resting recordings at orientation and on the experimental day, as well as between rest and during task performance during the experimental day. ICCs were significant for both HR and RSA. See Appendix L for first order correlations between cardiac measures at all time points.

Table 10

ICC for HR and RSA for ECG at Rest and During Task Performance

	Control				SR			
	n	ICC	*p*	95% CI	n	ICC	*p*	95% CI
HR	35	.932	<.001*	.887-.963	32	.939	<.001*	.896-.967
RSA	35	.910	<.001*	.849-.950	32	.882	<.001*	.797-.937

Note. ICC = Intraclass Correlation Coefficient; CI = Confidence Interval

Mean HR and RSA values are noted in Table 11. Group (C, SR) by Time (Orientation, Main experimental day) ANOVAs showed no Group differences in either HR or RSA between Groups for baseline cardiac measures as a result of the sleep manipulation (Figure 8). Group (C, SR) by Time (Main experimental day, Face Task, IAPS Task) mixed model ANOVA testing of HR showed a significant interaction, F (2, 130) = 3.18, p = .05 η^2 = .05. To clarify the interaction, t-tests were conducted with difference scores (task – baseline) to each task; there were group differences in the extent of HR slowing in response to task demands for both the Face Task (t (66) = 2.63, p = .01) and the IAPS Task (t (66) = 2.23, p = .03). There was a larger decrease in HR in response to task in the SR group relative to controls.

Table 11

Mean HR and RSA by Experimental Condition

	Control		SR	
	n	M (SD)	n	M (SD)
HR_O	36	71.65 (9.49)	36	71.34 (8.36)
HR_M	37	72.09 (8.04)	35	72.84 (8.46)
HR_F	35	71.74 (8.55)	33	71.05 (8.71)
HR_I	34	69.15 (8.88)	31	67.74 (7.46)
HR $Reactivity_F$	33	-0.19 (4.16)	32	-1.89 (3.95)
HR $Reactivity_I$	33	-3.88 (4.41)	31	-5.87 (4.37)
$Respiration_O$	36	14.82 (3.38)	36	13.96 (2.93)
RSA_O	36	6.91 (1.02)	36	6.85 (0.85)
RSA_M	37	6.58 (0.92)	35	6.56 (0.74)
RSA_F	35	6.30 (0.99)	33	6.32 (0.90)
RSA_I	34	6.99 (0.88)	31	7.05 (0.77)
RSA $Reactivity_F$	31	-0.29 (0.80)	29	-0.29 (0.66)
RSA $Reactivity_I$	33	0.45 (0.53)	31	0.49 (0.46)

Note.[10] Subscripts denote the ECG recording condition:
O = Orientation baseline; M = Main experimental day baseline;
F = Face Task; I = IAPS Task.

[10] RB12 excluded from all cardiac analyses. Cases excluded from task analyses were also excluded from reported means in Table 11: Face task exclusions KE64, VS51, AG85 and KH102; IAPS task exclusions CB16 and AG85.

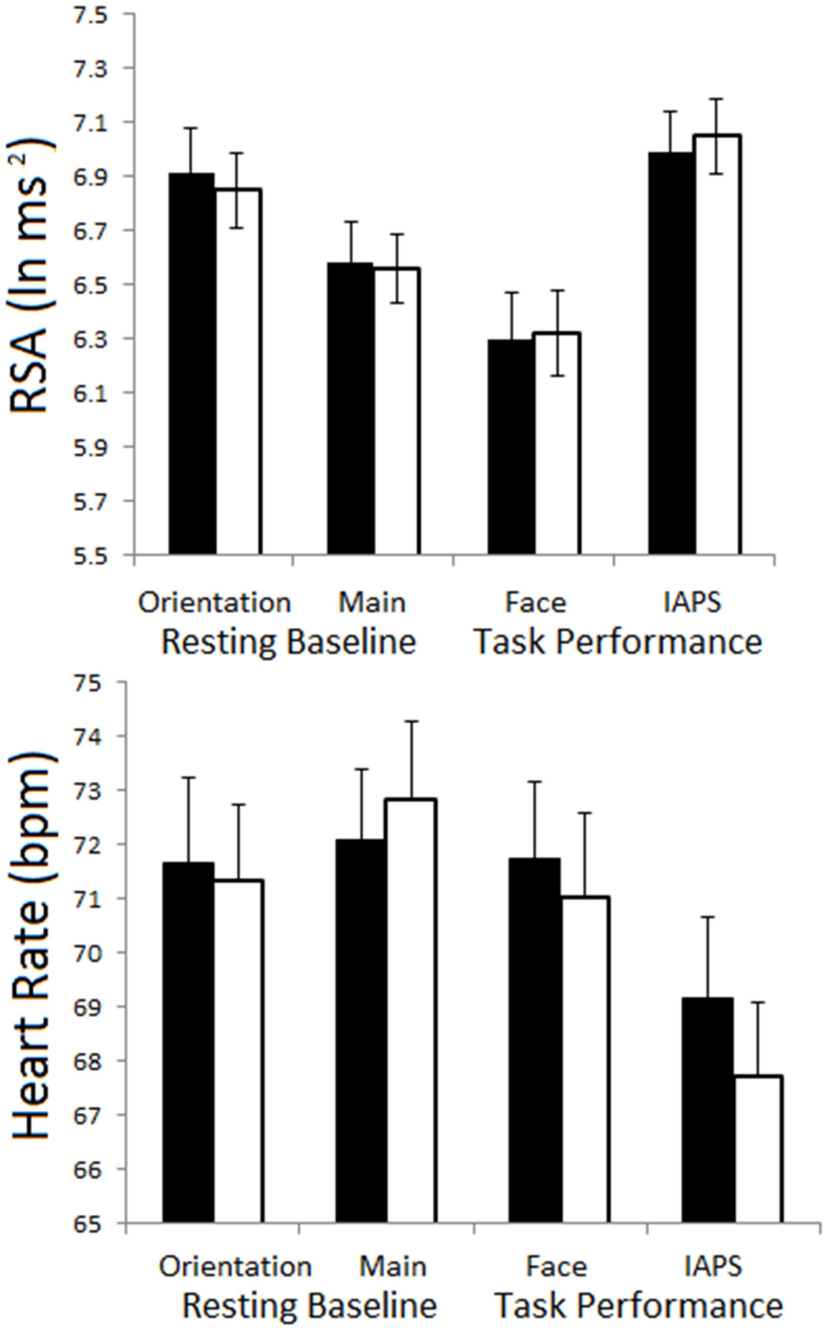

Figure 8. RSA and HR at resting baseline (Orientation, Main experimental day), and during task performance (Face Task, and IAPS Task).
Control = solid bars; SR = open bars. Error bars represent Standard Error.

In summary, sleep restriction did not impact resting RSA or HR measures when comparing the baseline recording at the Orientation session and the recording during the Main experimental day. There was, however, evidence of greater HR slowing in response to emotion processing tasks in the SR group relative to the Control group on the experimental day.

Relation of Cardiac Measures to Affective Style

Regression analyses of HR and RSA with measures of affective style revealed a trend for an association between higher RSA_O and lower scores on a measure of impulsivity—Barratt's Impulsiveness Scale (BIS-II), F (1, 67) = 3.36, p =.071, R^2 = .06. Resting RSA_O (prior to the sleep manipulation) accounted for 6% of the variance in the total BIS-II score. Examination of subscales revealed a significant correlation between RSA_O and the Non-planning Impulsiveness subscale, r = -.27, p = .03.

There were no other significant associations between baseline RSA and measures of personality or affective style; it may be that the sample size (n = 74) did not provide sufficient power to explore those measures.

Predicting RT with Cardiac Measures

RT and Cardiac Measures on the PVT. First order correlations revealed significant associations between resting RSA_O and mean RT on the PVT, as well as between HR and 10% Slowest RT in the SR group, shown in Table 12.

Table 12

Correlations between Cardiac Measures and Performance on the PVT

	Control				SR			
	Mean RT	SD RT	10% Fast	10% Slow	Mean RT	SD RT	10% Fast	10% Slow
HR_O	.190	.200	.183	-.260	-.316†	-.230	-.302†	.319†
HR_M	.231	.157	.243	-.277	-.242	-.249	-.205	.278
HR_F	.119	.091	.137	-.181	-.230	-.290	-.142	.311†
HR_I	.075	.114	.060	-.175	-.230	-.320	-.148	.375*
RSA_O	-.105	-.080	-.145	.135	.419*	.070	.342*	-.218
RSA_M	-.146	-.056	-.203	.127	.388*	.221	.182	-.314†
RSA_F	.008	-.066	.004	.095	.348*	.192	.127	-.291†
RSA_I	-.020	-.015	-.080	.056	.361*	.157	.188	-.298

Note. Correlations refer to transformed RT variables[11]
* = $p < .05$, † = $p < .10$

Regression analyses were carried out in order to further examine the possible role of HR and RSA as moderators of the effect of sleep restriction on performance on the PVT. RSA_O was investigated as a moderator of the effect of SR on mean RT; and a second analysis examined HR_O as a moderator of the effects of SR on the slowest RTs[12].

An initial regression was carried out with possible covariates entered stepwise on the first step. Neither Age, Sex, BMI, nor Exercise accounted for significant variability in the model and were thus discarded from the final regression. Two possible outliers were identified in the model, the model remained significant with the potentially influential cases included or excluded; thus, it was decided to retain those cases in the final model as they represented valid cases and their inclusion did not alter the significance of the model.

[11] Mean RT, SD RT, 10% Fast underwent Log 10 transformation; 10% Slow underwent an inverse transformation. AG85 and RB12 were excluded from the analysis.

[12] The 10% Slow variable was computed by averaging the 10% longest responses times on the PVT.

The regression model was significant, F (3, 65) = 30, p = .037, R^2 = .12; RSA_O moderated the effect of sleep restriction on (transformed) Mean RT. The model accounted for 12% of the variance in mean RT on the PVT, and can be visualized in Figure 9.

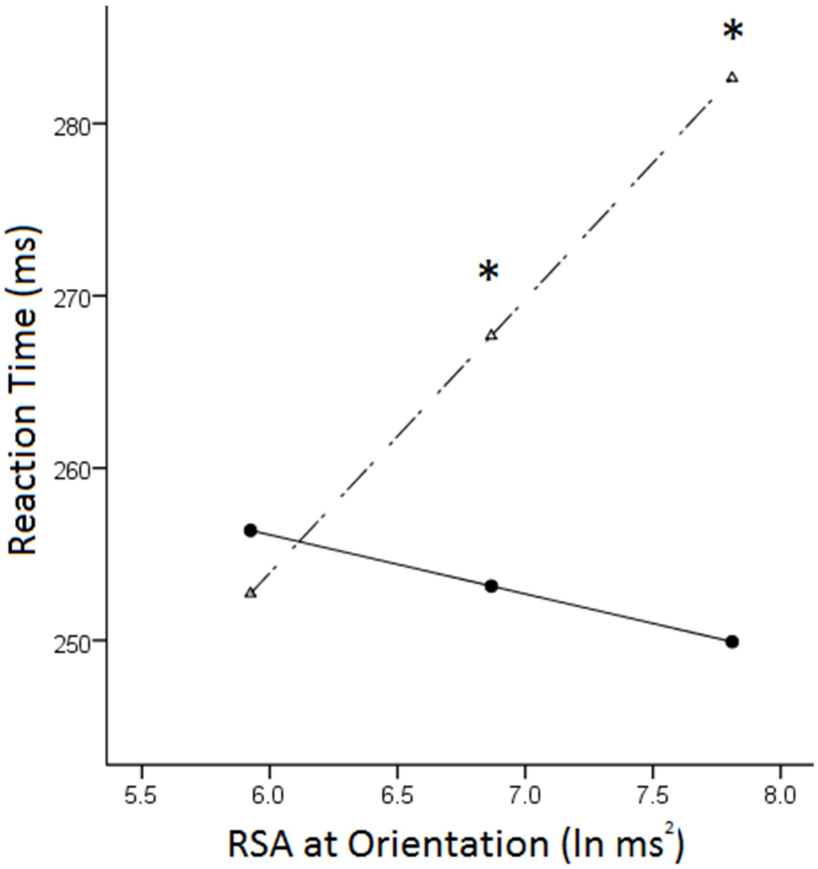

Figure 9. Means plot showing moderation effect of baseline RSA on the relationship between sleep restriction and mean RT during a PVT. Moderate to high RSA in the sample of healthy, young adults was associated with longer RT in SR participants only. During the task participants were asked to hit the "0" key on a keyboard as quickly as possible in response to a tone. SR = Δ (broken line); C = ● (solid line). * = regions of significance.

Further examination of the fastest and slowest responses on the PVT revealed a significant model wherein HR_O interacted with group (SR, C) in predicting the average of the 10% slowest RTs (inverse transformed). Three cases were identified as possible outliers; however, the model remained significant with and without their inclusion and thus they were retained in the final model. Sex was entered into the model as a covariate; exploratory analyses confirmed that sex did not interact with either group or HR_O.

In the final model, HR_O moderated the effect of sleep restriction on (transformed) average RT of the 10% slowest responses, F (4, 65) = 4.74, p = .002, R^2 = .18. The model accounted for 18% of the variance in the 10% slowest responses on the PVT, and can be visualized in Figure 10.

In summary, cardiac measures accounted for variability in performance on a simple RT task between SR and Control groups. SR participants with moderate to high RSA_O had longer mean RT to the PVT; SR participants with lower HR_O demonstrated longer RT to the 10% slowest responses on the PVT relative to Controls. RSA was derived from the beat-to-beat variability in the HR; higher RSA and lower relative HR together are consistent with increased PNS influence on the heart. The interaction of HR and RSA on RT provides support for these measures as meaningful metrics to predict individual differences in response to sleep loss.

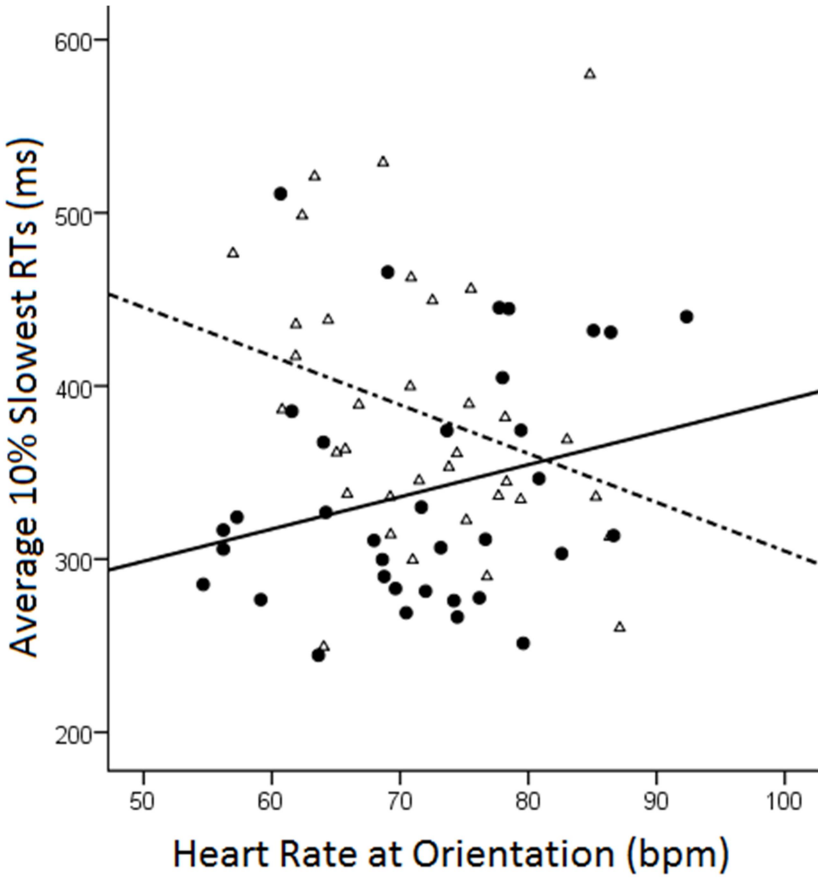

Figure 10. Scatterplot of 10% slowest RT with HR_O by Group. Lower HR at baseline was associated with slower RT in SR and faster RT in Controls when evaluating just the 10% slowest responses on the simple RT task.
SR = Δ (broken line); C = ● (solid line).

Predicting Emotional Processing with Cardiac Measures

RT and Cardiac Measures on the Face Task. Pearson correlations were calculated between (transformed) RT to Emotional Faces (combined to 40-60% Intensity stimuli) and cardiac measures (Table 13)[13]. Significant correlations were examined and used to guide regression strategies to explore possible relations between cardiac variables and performance on the Face Task.

Table 13

Correlations between Cardiac Measures and RT to Face Task by Emotion Type

	Control				SR			
	Happy (√ms)	Sad (√ms)	Fear (√ms)	Angry (√ms)	Happy (√ms)	Sad (√ms)	Fear (√ms)	Angry (√ms)
HR_O	-.045	.179	.008	.067	-.091	-.071	.009	-.075
HR_M	.258	.405*	.180	.312	-.152	-.308	-.110	-.193
HR_F	.194	.352*	.187	.250	-.270	-.436*	-.298	-.405*
HRR_F	-.108	-.071	.035	-.100	-.259	-.280	-.365*	-.407*
RSA_O	.388*	.170	.269	.190	-.032	-.075	-.030	.032
RSA_M	.160	-.019	.061	.015	.031	.128	.033	.186
RSA_F	.250	-.010	.169	.148	.201	.251	.295	.319
$RSAR_F$	.107	-.017	.145	.166	.285	.215	.342	.212

Note. * $p < .05$

Regression analyses were carried out to explore the pattern of correlations between HR and RT to identification of emotional Face Type; Figure 11 depicts the moderation model tested in the analyses.

[13] Excluded from analysis: RB12, KE64, VS51, AG85, and KH102.

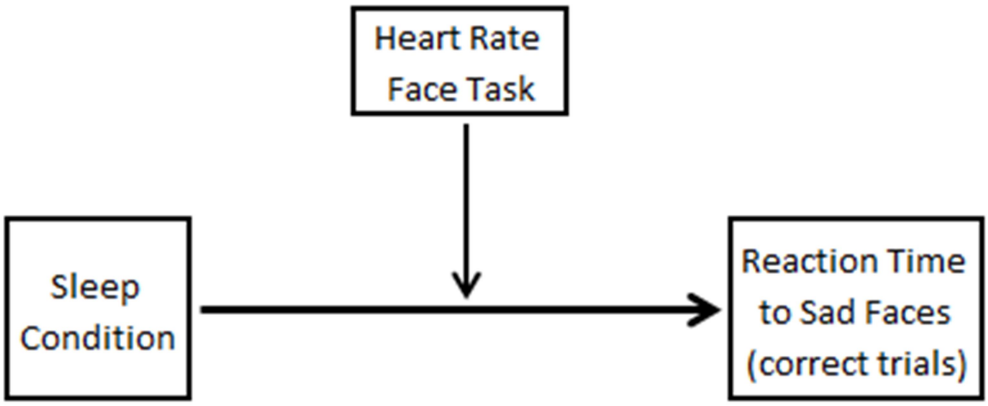

Figure 11. Model to test the role of HR_F as a moderator of the effect of condition on task performance.

Regression analyses were conducted with (transformed) RT to each Emotion Type in the Face Task by Group (C, SR) and task HR_F; as well as a separate set of analyses with Group and HRR_F (reactivity) to the task were carried out (Appendix M). Multivariate outliers were identified and removed from the final analysis[14]. The regression of HR_F, Group, and the interaction term (HR_F x Group) on RT was significant for Sad face stimuli, F (3, 63) = 3.42, p = .02, R^2 = .14; the model accounted for 14% of the variance in RT to Sad faces. Figure 12 shows the scatterplot of the significant interaction. Lower HR during the Face Task was associated with slower RT to Sad faces in SR and the opposite—faster RT to Sad faces—in controls. Recall that accuracy for identification of Sad faces was significantly lower for SR compared to controls.

[14] Excluded from analysis ND50, ME44, RB12, KE64, VS51, AG85, and KH102.

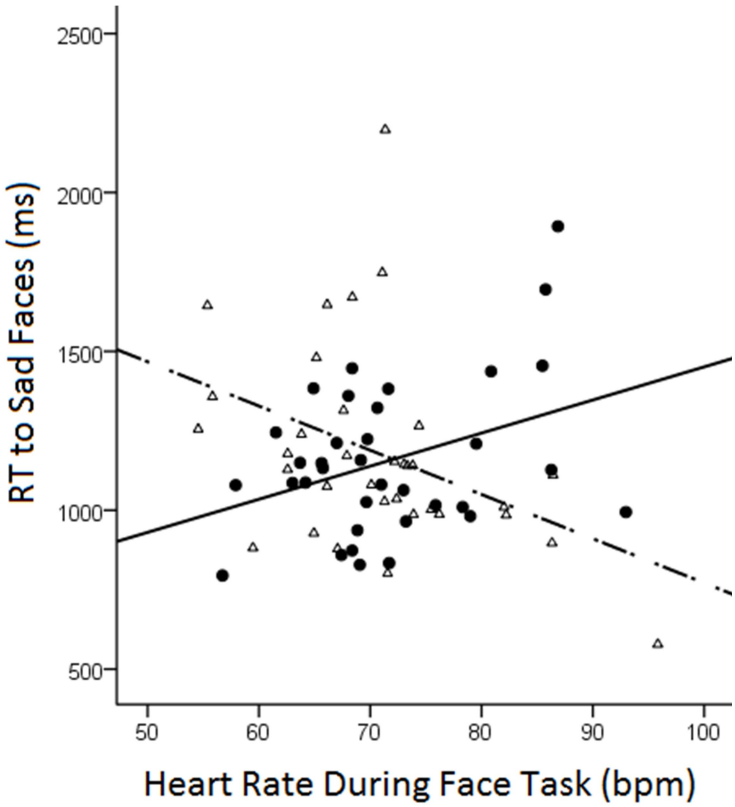

Figure 12. HR during the Face Task interacted with Group (SR, C) to predict RT to correctly categorized Sad faces; SR with lower HR on task demonstrated slower RT to Sad faces while Controls with lower HR on task had faster RT to Sad faces.
Control = ● (solid line); SR =Δ (broken line).

RT and Cardiac Measures on the IAPS Task. RSA during the IAPS task was entered into a regression model with Group (SR, C) to predict RT to the task[15]. Exploratory analysis with covariates indicated that Sex accounted for variability in the model; however, there were no interactions between Sex and Group or Sex and RSA_I. Regression results are summarized in Table 14. RSA_I acted as a moderator on the relationship between group and RT to Negative stimuli. Although the models for Neutral and Positive were significant overall, the Group by RSA_I interaction was non-significant at entry into the model for Neutral stimuli and showed as a trend for Positive stimuli (Figure 13). Higher task RSA was associated with longer RT in the Control group for Negative stimuli and to a lesser extent with Positive stimuli; examination of the plots in Figure 13 show a similar high RSA_I/long RT association for Neutral stimuli for both SR and Control groups.

[15] Excluded from analyses RB12, CB16, AG85, DG31 and MK101; Additional case excluded from Negative AP30; Additional cases excluded from Neutral BM24 and SW95.

Table 14

Regression of Group on RT to IAPS Task with Task RSA as a Moderator

	Step		*B (SE)*	R^2	*F Δ*	*df1*	*df2*	*p*	*F*	*df*	*p*
Negative	1	Sex	-317.81 (109.92)*	.12	8.36	1	60	.005*	8.36	1, 60	.005*
	2	Group	-56.74 (96.26)								
		RSA_I	134.85 (65.61)*	.18	2.24	2	58	.116	4.39	3, 58	.007*
	3	Group*									
		RSA_I	-263.54 (126.61)*	.24	4.33	1	57	.042*	4.57	4, 57	.003*
Neutral	1	Sex	-244.46 (117.66)*	.07	4.32	1	59	.042*	4.32	1, 59	.042*
	2	Group	-32.98 (101.14)								
		RSA_I	160.71 (69.94)*	.15	2.66	2	57	.079†	3.29	3, 57	.027*
	3	Group*									
		RSA_I	-115.44 (139.58)	.16	.68	1	56	.412	2.63	4, 56	.044*
Positive	1	Sex	-254.69 (110.86)*	.08	5.28	1	61	.025*	5.28	1, 61	.025*
	2	Group	-53.14 (95.17)								
		RSA_I	162.94 (65.39)*	.17	3.21	2	59	.048*	4.02	3, 59	.011*
	3	Group*									
		RSA_I	-223.82 (127.54)†	.21	3.08	1	58	.085†	3.89	4, 58	.007*

Note. B values are the unstandardized coefficients at entry into the model.
Independent variables were coded as 0/1: control/SR and male/female respectively.
* = $p < .05$, † = $p < .10$

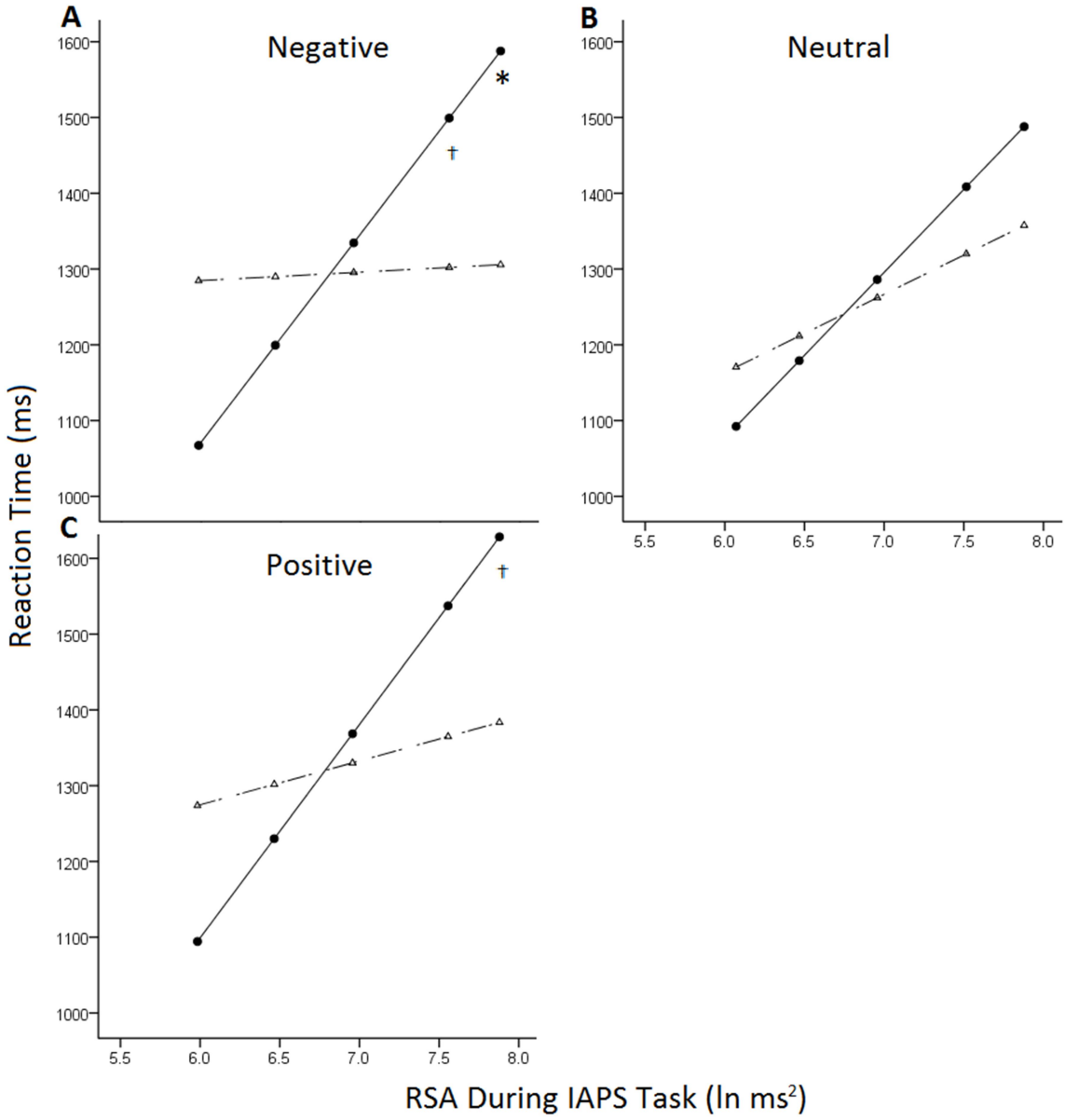

Figure 13. A: RT to Negative Pictures with a significant interaction (*) between RSA_I and Group.
B: RT to Neutral Pictures (no significant interaction).
C: RT to Positive Pictures with a trend (†) towards a significant interaction between RSA_I and Group.
Control = ● (solid line); SR = Δ (broken line)

N170 to Emotional Faces and Cardiac Measures. Regression analyses investigating the hypothesized contribution of sleep condition (Group) and RSA_O to N170 amplitude were conducted according to the strategy outlined in Appendix I. RSA_O was divided into high and low groups based on a median split. No covariates accounted for significant variance in the exploratory stage of analysis and were thus not included in the final models.

Analyses conducted at PO4, PO6, and PO8 resulted in significant models, at all sites for Group (SR, C) and low/high RSA_O as predictors of the N170 to emotional faces (see regression tables in Appendix N)[16]. Effects were most robust at PO4. In order to confirm that effects were not due to general relations between RSA and N170 ERPs, first order correlations between cardiac measures and N170 amplitude were calculated and appear in Appendix O.

RSA_O moderated the relationship between Group (SR, C) and N170 amplitude at PO4 to Happy (interaction $p = .004$), Fearful (interaction $p = .007$), and Angry (interaction $p = .012$) Emotional Face Types; there was a trend for Sad Faces (interaction $p = .054$). Interactions at PO4 are depicted in Figure 14.

[16] Excluded from analyses RB12, DG31, KE64, KK58, RR84, VS51, AS47, KB67, KH102, SW95, and UH117; BB118 excluded from Sad N170 analyses; YS13 excluded from Happy N170 analyses.

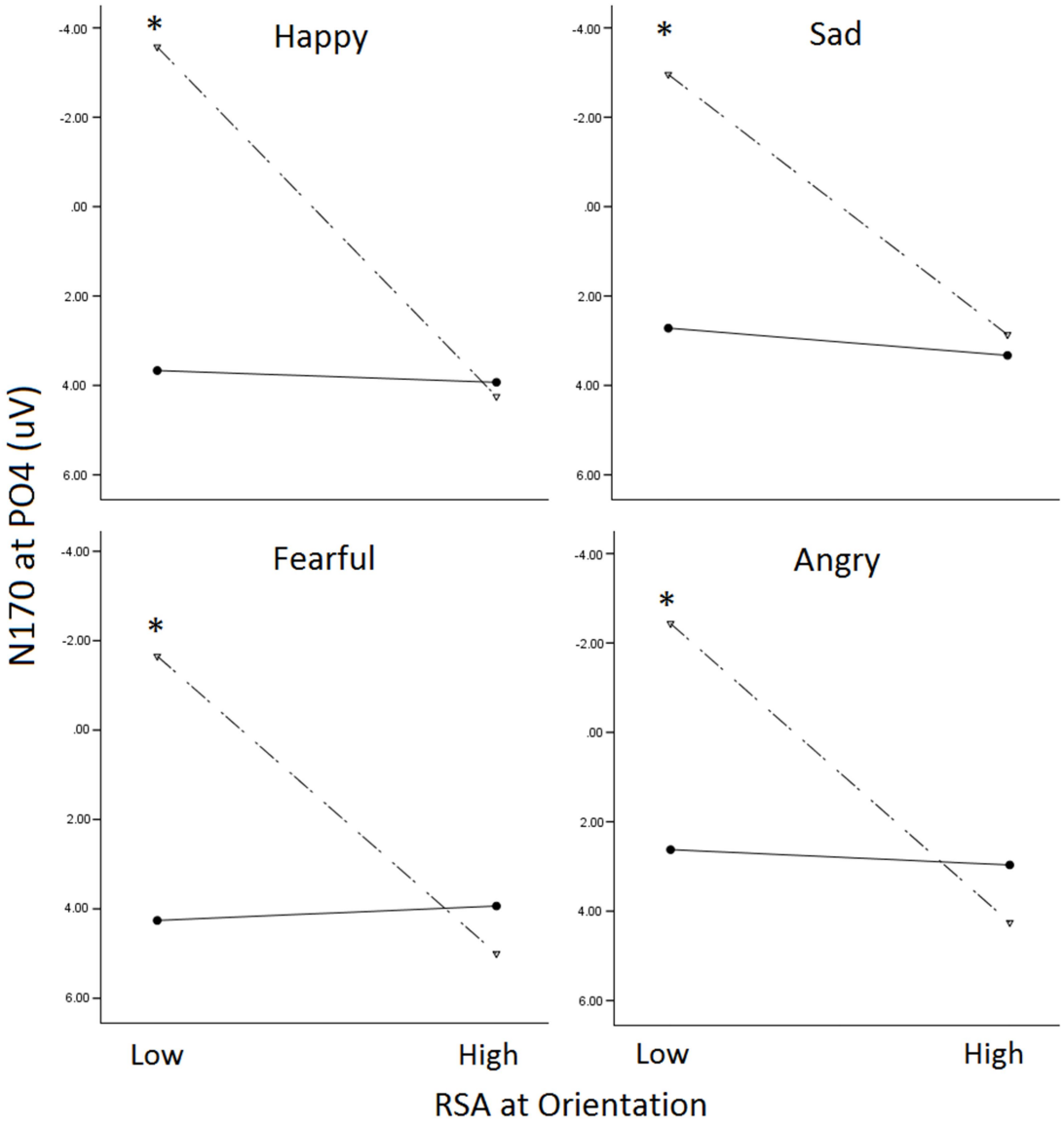

Figure 14. RSA was a moderator of the relationship between Group and N170 amplitude to Emotional Faces; Low RSA in the SR group was associated with larger (more negative) N170 to Emotional Faces. Significant effects at low RSA denoted with *, note that the model for Sad was a trend at $p = .054$.
SR = Δ (broken line); Control = ● (solid line).

As a follow up to the moderation analysis reported above, N170 amplitude to Emotional Faces was also examined separately at the 40, 50, and 60% Intensity of expression. Due to lower number of trials in the averages for these ERPs when examined within intensity level, they were examined with caution, but are presented in a figure in Appendix P to provide visual confirmation that the moderation effect was not isolated to higher or lower Intensity of expression.

LPP to IAPS Pictures and Cardiac Measures. A regression analysis examined the hypothesized role of high/low baseline RSA as a moderator of Group (SR, C) differences in neural responses to IAPS Emotional Pictures[17]. Analysis focussed on the difference between LPP amplitude to Positive – Neutral pictures, where group differences were identified as a larger LPP to Positive relative to Neutral pictures in the SR compared to Control group.

The regression model summarized in Table 15 was significant; the interaction between Group and high/low RSA_O on the Positive-Neutral difference score accounted for variance beyond that accounted for by Group alone: at entry into the model, the interaction term showed a trend towards significance. As with the previous ERP analysis, first order correlations between cardiac measures and LPP amplitude were calculated in order to confirm that relations were not driven by a general pattern of correlations between RSA and the ERP component of interest (Appendix O).

[17] Excluded from analysis RB12, CB16, and AG85.

Table 15

Regression of Group on LPP (Positive-Neutral) with RSA as a Moderator

Step		*B (SE)*		R^2	*F Δ*	*df*	*p*	*F*	*df*	*p*
1	Group	2.04	(.97)*							
	RSA_O	-1.47	(.97)	.09	3.47	2, 67	.037*	3.47	2, 67	.037*
2	Group*RSA_O	-3.30	(1.91)†	.13	3.00	1, 66	.088†	3.38	3, 66	.023*

Note. B values are the unstandardized coefficients at entry into the model.
RSA_O was coded as 0/1 for low/high RSA determined by a median split.
* = $p < .05$, † = $p < .10$

The interaction between high/low RSA_O and Group on the Positive-Neutral LPP difference score is depicted in Figure 15.

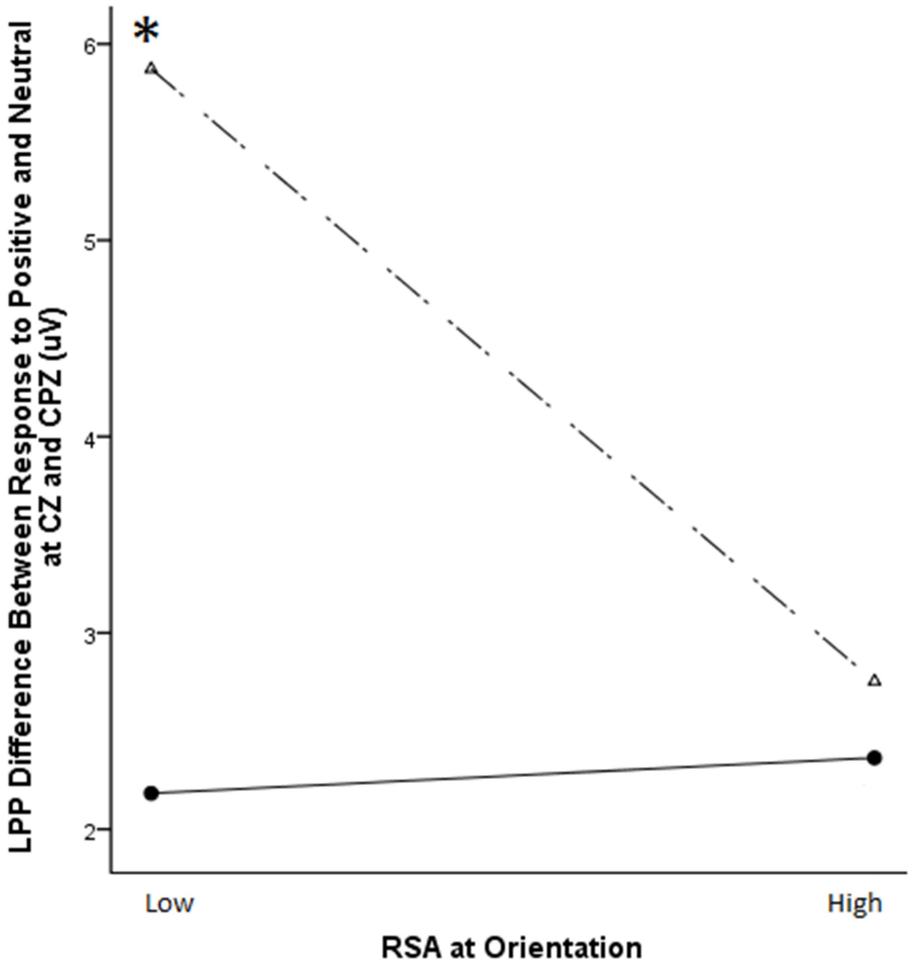

Figure 15. RSA moderated the relationship between SR and the LPP Difference Score (Positive-Neutral) in response to IAPS pictures. The larger LPP was associated with low resting RSA in SR only, denoted with an *.
SR = Δ (broken line); Control = ● (solid line).

RSA at baseline (prior to sleep restriction) moderated the relationship between Group (SR, C) and ERP responses to emotional stimuli. For the Face Task, low RSA_O predicted a larger N170 in SR participants; for the IAPS Task, low RSA_O predicted a larger LPP to Positive pictures in SR participants (larger difference between the LPP to Positive relative to Neutral).

Predicting Emotional Processing with Measures of Cardiac Functioning and Affective Style

Personality and affective style as indexed by questionnaire scores were explored with residual plots from regression models detailed above. Both subscales of the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003; Appendix Q), Reappraisal (ERQ-R) and Suppression (ERQ-S), appeared to relate to the model and were thus integrated into a larger regression model, see Figure 16 for an overview of the model tested

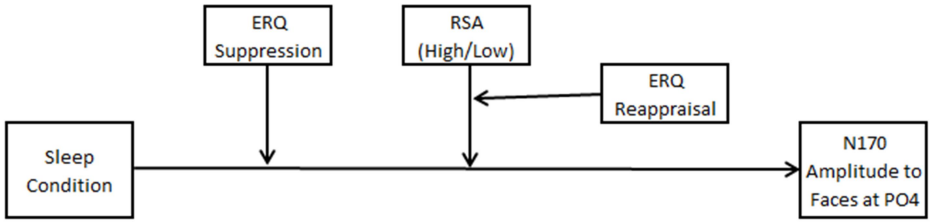

Figure 16. Model for Regression of Group on N170 Amplitude to Emotional Faces with RSA_O, ERQ-Suppression, and ERQ-Reappraisal as Moderators.

Examination of ERQ-S and ERQ-R scores confirmed the scale scores were independent of each other (r = .07); RSA_O was not correlated with either ERQ-S (r = .05) or ERQ-R (r = .01) scores. Significance of first order correlations was not affected by Group (SR, C).

Covariates (Age, Sex, BMI, Respiration) were entered stepwise on Step 1 in a hierarchal regression; Step 2 included variables of interest (RSA_O, Group, ERQ-S, ERQ-R); Step 3 included four 2-way interaction terms (Group by RSA_O, ERQ-R by RSA_O, ERQ-S by Group, and ERQ-R by Group), Step 4 included a 3-way interaction term (Group by ERQ-R by RSA_O)[18].

For the purpose of visualization the regression was graphed in two stages: First, in Figure 17, N170 amplitude was regressed on sleep condition with ERQ-S entered as a moderator; and second, in Figure 18, N170 amplitude was regressed on sleep condition with ERQ-R and RSA_O entered as interacting moderators.

The regression models were significant for each Emotional Face Type (Happy, Sad, Fearful, and Angry) at $p < .001$. Regression analyses are detailed in Appendix R. The models show low ERQ-Suppression scores were associated with a larger (more negative) N170 in SR participants only; high ERQ-Reappraisal scores and low RSA_O were associated with a larger (more negative) N170 again in SR participants.

[18] Excluded from analyses RB12, DG31, KE64, KK58, RR84, VS51, AS47, KB67, KH102, SW95, and UH117; BB118 excluded from Sad N170 analyses; YS13 excluded from Happy N170 analyses. Additional multivariate outliers removed from the analyses include HA46, RI112 and VB09. ST36 and SD70 were removed for Angry only.

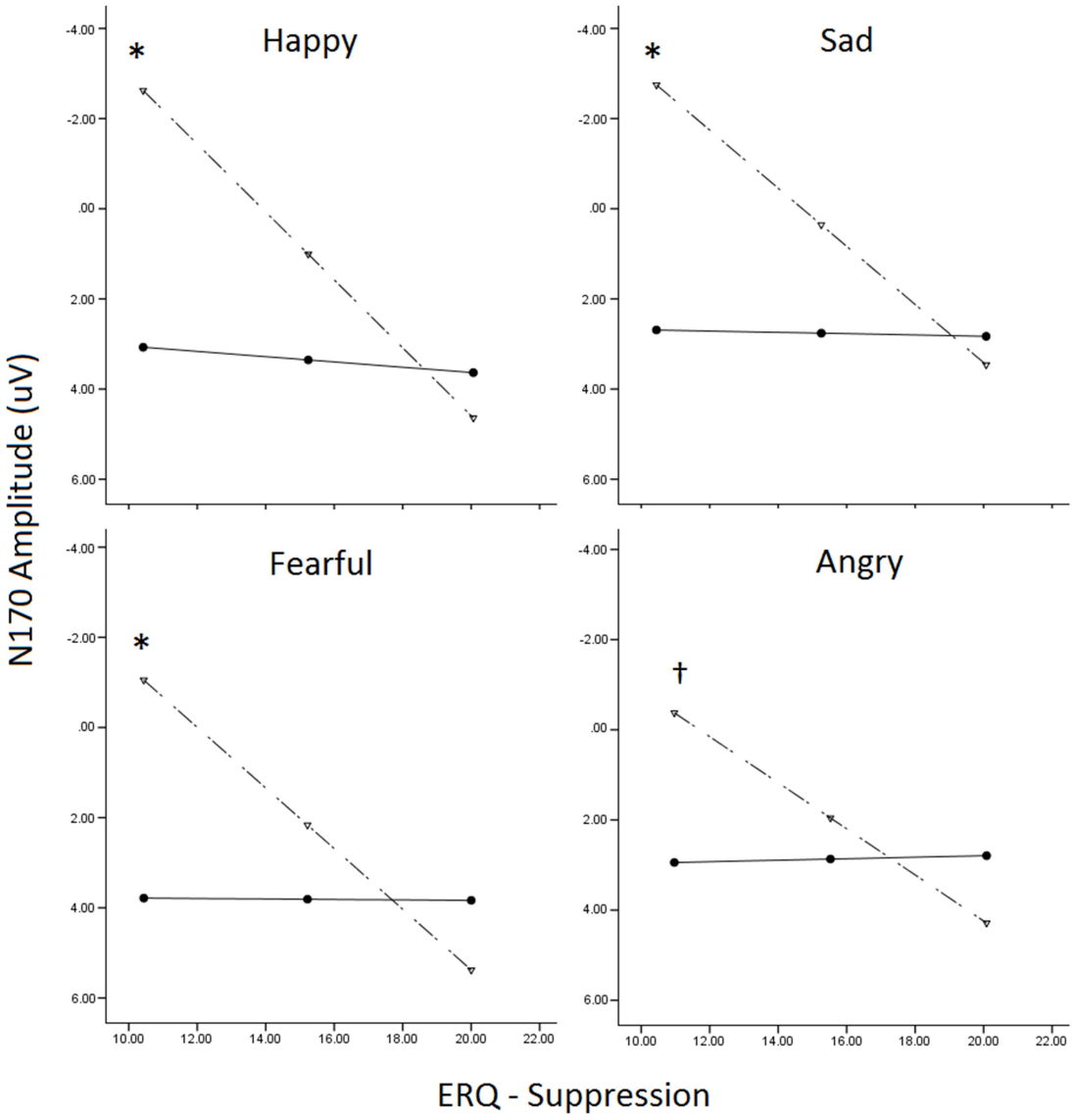

Figure 17. In the depicted model low ERQ Suppression scores were associated with a larger N170 (negative is up on the y-axis) at PO4 in response to Happy, Sad and Fearful faces in SR participants, with a trend for Angry faces. Regions of significance denoted with * and trends denoted with †. SR = Δ (broken line); Control = ● (solid line)

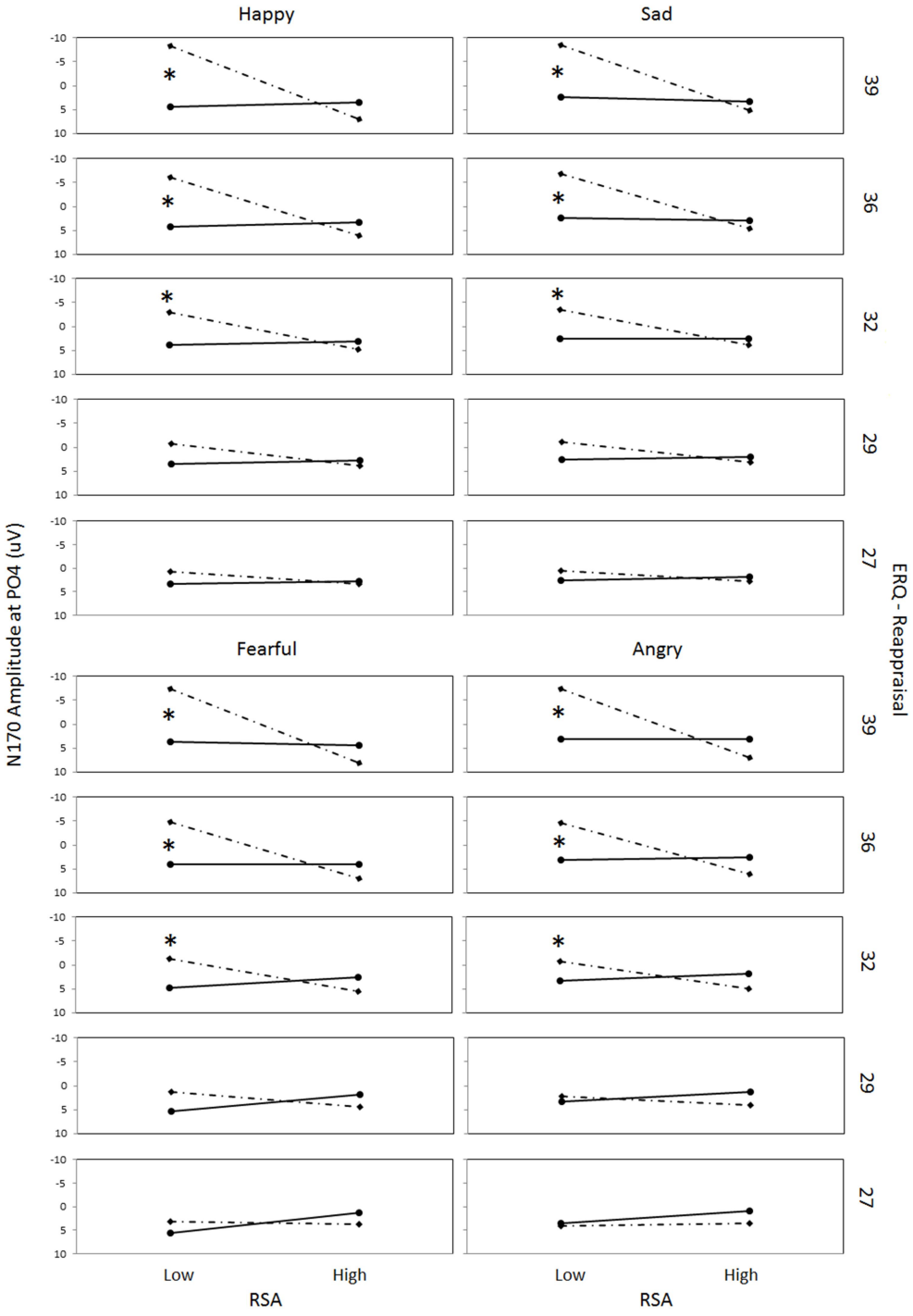

Figure 18. In the depicted model low RSA at baseline and high ERQ Reappraisal scores were associated with a larger N170 at PO4 in response to emotional faces in SR participants (more negative ERP amplitude is shown as up on graphs). Regions of significance denoted with *. SR = Δ (broken line); Control = ● (solid line)

Discussion

The focus of the current study was to investigate the role of RSA as a predictor of individual differences in vulnerability to sleep loss, particularly with reference to changes in emotion processing. A naturalistic sleep restriction was used to examine the impact of a short (4-hour) night of sleep in the home environment on next day functioning. The degree of sleep restriction used in the study was quite subtle, lending interest to small but significant findings. Multiple measures were used to assess response to sleep loss and particularly impact on emotion processing. RSA provided insight into individual differences for vulnerability to sleep loss in the context of neural responses to emotional stimuli.

Sleep loss has long been understood to be associated with impairments in performance (Patrick & Gilbert, 1896). Research has provided evidence of mood changes associated with sleep loss that until recently relied on subjective state reports (Pilcher & Huffcutt, 1996). Recent reviews on the topic of sleep and emotion reflect increased interest in clarifying mechanisms relating sleep loss to alterations in mood and changes in emotion processing (Beattie et al., 2015; Khan, Sheppes, & Sadeh, 2013; Vandekerckhove & Cluydts, 2010; Walker, 2009). Of particular interest is sleep loss associated impairment of prefrontal cortical regions that are implicated in top-down regulation of subcortical structures such as the amygdala and other components of the limbic system (Vandekerckhove & Cluydts, 2010).

Top-down control of subcortical regions has been related to self-regulation in a broad sense, and has been linked specifically to addiction, emotion regulation, and

decision making (Heatherton & Wagner, 2011). A recent meta-analysis (Zahn et al., 2016) provided support for a relationship between HF HRV and self-regulation in line with the theoretical conception of HF HRV as an indicator of vagal tone that is related to pre-frontal cortical structures involved in cognition, attention, and emotion regulation (Thayer & Lane, 2000).

Research reviewed on sleep loss and emotion regulation informed hypotheses regarding the utility of RSA, an index of vagal tone reflecting self-regulatory capacity, as a moderator of the effect of sleep restriction on emotion processing. Specific hypotheses and outcomes are detailed below.

Effects of Sleep Restriction on Subjective Sleepiness, Mood, and RT

The first hypothesis stated that one night of sleep restriction would be sufficient to impact alertness and subjective mood states. There was support for the effects of the sleep restriction manipulation in that participants reported increased sleepiness and decreased positive affect relative to controls on subjective state measures after one night of restricted sleep. Sleep restricted participants endorsed lower positive affect on the PANAS and on visual analog mood scales, as well as feeling less calm/more irritable, less happy/more sad, less energetic/more sluggish, and less relaxed/more tense than control participants. On the PVT, a simple reaction time task, sleep restricted participants' performance was slower and more variable than rested control participants' performance; sleep restricted participants demonstrated slower mean RT with larger standard deviations, and there were particularly notable group differences when looking at the slowest responses on the task (10% slow). These findings are consistent with

previous research that has shown changes in subjective state and performance measures after a single night of sleep restriction (Belenky et al., 2003; Dinges et al., 1997; Van Dongen et al., 2003).

Effects of Sleep Restriction on Emotional Processing

It was hypothesized that sleep restriction would be associated with alterations in performance to emotional processing tasks in terms of behavioural and psychophysiological outcome measures. Based on previous research (Cote et al., 2015; Cote et al., 2014), it was expected that performance would be impacted to a greater degree to stimuli with negative valence and that responses to sad face stimuli would be distinct from responses to threat-relevant face stimuli.

Face Task. On the emotional face task, all participants had more difficulty identifying the sad and angry expressions than happy or fearful expressions, which is consistent with previous research that has identified fear and happiness as easier to discriminate than other emotions (Adolphs, 2002); sleep restricted participants compared to rested controls demonstrated larger impairments in their ability to identify both sad and angry expressive faces. Impairment for recognition of specific emotions may be due to subtlety of the expression; for instance, sad faces may share more common features with neutral faces and thus could be described as more ambiguous than happy faces. Ambiguity in an emotional face may impair performance on an emotion identification task as a function of perceptual difficulty, or may indicate that ambiguous expressions require differential cognitive demands compared to emotions that are more salient under condition of sleep deprivation (Adolphs, 2002).

In previous research in the Brock Sleep Research Laboratory, participants who had been sleep deprived for one night (31.5 hours awake) showed deficits in identification of sad faces, but were comparable to controls in their ability to identify happy, angry and fearful faces (Cote et al., 2014). In another study, a single night of sleep deprivation (31 hours awake) was associated with impaired accuracy at identification of happy and angry expressions, while performance was left intact for sad (van der Helm et al., 2010). There were several methodological differences between each study and the present research that may account for differences: the amount of sleep loss differed between paradigms (sleep restriction to 4-hours on 1 night vs. 31 hours awake); stimuli were presented in mixed (present thesis, Cote et al., 2014) or block design for each emotion (van der Helm, et al., 2010); and, task parameters were different (identify emotion with neutral response option, identify emotion without a neutral option, identify on gradient from neutral to expressive). Taken together, sleep loss impacted perception of emotionally expressive faces in a differential manner. It seems likely that the degree of sleep loss along with contextual and task demand factors play a role in the behavioural outcomes on emotion processing tasks, which reaffirms the necessity of examining objective, neural measures of emotion processing in order to gain an understanding of how sleep loss affects these processes.

There was evidence of differential neural processing of visual stimuli among the groups based on the ERP responses to the Face Task. The results of the present research suggest that sleepy participants' attention was captured more by happy and sad faces (larger N170), while responses to threat-relevant (fearful and angry) faces, remained relatively intact (comparable to controls). The pattern of response to different emotions

was also quite different in sleep restriction compared to control: while control participants showed similar N170 amplitudes across happy, sad, and fearful faces, with slightly larger responses to angry faces, sleep restricted participants' responses to sad and happy faces were distinctly larger than that to threat-relevant (fearful and angry) faces. A larger N170 response to emotional faces is consistent with increased activation in cortical visual processing areas (Palermo & Rhodes, 2007), which can be interpreted as larger attention capture for processing of facial features in response to happy and sad faces in the sleep restriction group. Sleep restriction did not elicit enhanced response to fearful and angry faces in contrast to research showing preferential processing of threat-relevant stimuli in ERP studies (Palermo & Rhodes, 2007), including in response to total sleep deprivation (Cote et al., 2014); however, the study design of a single night of sleep restriction was quite different from a total sleep deprivation or chronic (multiple night) sleep restriction design.

In summary, taken with the behavioural outcomes on the Face Task, it appears that sleep restricted participants had larger neural response to happy faces, and this was associated with intact performance for identification of happy faces; sleep restricted participants had larger neural response to sad faces, and were not able to identify sad faces as accurately as control participants; neural response to fearful and angry faces were similar in sleep restricted and control participants, but sleep restricted participants had greater difficulty identifying angry expressions. Performance was impaired on the behavioural task to identify sad faces despite larger N170 ERPs to sad faces, suggesting sad faces elicited increased attentional resources perhaps due perceptual difficulty or increased cognitive demand to assess this particular emotional expression. In contrast,

angry faces, which were also difficult for sleep restricted participants to identify, did not show differences in N170 amplitude compared to the control group. It could be that resources being allocated to other types of stimuli (happy, sad) may have impacted performance for angry faces.

IAPS Task. Behavioural responses on the IAPS Task were assessed for accuracy and reaction time to instructions to classify stimuli as positive, negative, or neutral. Accuracy on the task appeared to reach a ceiling effect for all categories, although there was a general effect of higher accuracy with negative stimuli. Participants in both groups were slightly more accurate at identification of negative stimuli, likely due to some ambiguity between positive and neutral stimuli (e.g., a picture of a coffee cup would correctly be classified as neutral but might be rated as positive by some participants).

A measure of sustained attention to stimuli, the LPP ERP, was investigated in response to emotional pictures from the IAPS picture set (Lang et al., 2008). Both control and sleep restricted participants showed larger LPP responses to emotional versus neutral pictures, consistent with previous research showing increased attentional resources to emotionally arousing stimuli (Hajcak et al., 2010; Olofsson et al., 2008; Schupp et al., 2006). In the sleep restriction group, there was increased LPP to positive relative to neutral pictures, suggesting that sleepy participants had difficulty modulating their responses specifically to positive stimuli. Previous research has found increased LPP to IAPS stimuli after a single night of total sleep deprivation, with larger effects for negative than positive images (Cote et al., 2015). MRI studies have provided evidence for increased activation of the amygdala and impaired connectivity between pre-frontal

cortical structures and the amygdala in sleep deprivation, resulting in enhanced reactivity to both negative (Yoo et al., 2007) and positive stimuli (Gujar et al., 2011).

In the current study, LPP response to negative relative to neutral stimuli appeared intact in sleep restriction relative to rested controls, while LPP response to positive relative to neutral stimuli was enhanced. This is consistent with emotional reactivity associated with sleep loss. Sleep restricted participants reported lower levels of positive affect, and may require more effortful attention to encode stimuli that is inconsistent with their subjective state. The LPP is thought to reflect selective attention, which inhibits activity in the visual cortex in order to dedicate resources to processing of the stimuli (Brown et al., 2012); thus more attentional resources being recruited to processing select stimuli results in less resource availability for competing stimuli with associated metabolic costs.

In summary, sleep restriction impacted emotion processing. Sleep restricted participants demonstrated behavioural impairments in the form of decreased ability to identify sad and angry facial expressions, and differential psychophysiological responses in the form of enhanced N170 to happy and sad faces, and greater difference in LPP to positive relative to neutral affective pictures.

Stability of Cardiac Measures and Relation to Affective Style

It was hypothesized that RSA at baseline (Orientation) and on the main experimental day would be stable, and that RSA at baseline would be related to measures of affective style. Tests of stability of cardiac measures confirmed that both RSA and HR were highly correlated over time in both the sleep restriction and control groups. Baseline

RSA, recorded pre-sleep manipulation, was related to self-reported impulsivity on Barratt's Impulsiveness Scale (Patton et al., 1995); higher RSA was associated with less impulsivity. This association is consistent with the conceptualization of RSA as a measure of adaptive functioning (Beauchaine, 2015). The sample may have lacked sufficient variability to identify further associations between RSA and affective style. In examination of positive affective style, using measures such as the PANAS, researchers recruited undergraduate students who were not screened for psychiatric, sleep, or other health conditions, along with slightly larger sample sizes of 80 to 98 participants (Oveis et al., 2009; Wang, Lu, & Qin, 2013), and in a larger study examining relations between habitual use of reappraisal and suppression, a sample of 151 women with a range of educational achievement was described (Spangler, Bell, & Deater-Deckard, 2015). In summary, RSA was stable over time and was associated with positive emotional style consistent with previous research.

Effects of Sleep Restriction on Cardiac Measures

It was hypothesized that RSA reactivity, or change between baseline and task performance would be greater for the sleep restriction group compared to rested controls, demonstrating greater parasympathetic nervous system withdrawal, as was seen in previous research with habitual short sleepers (Mezick et al., 2014). Contrary to the hypothesis, there was no evidence for an effect of sleep restriction on RSA reactivity from baseline compared to either the Face or IAPS Task; however, there was a more significant deceleration in heart rate between baseline and task in the sleep restriction group for both emotion processing tasks. This could be interpreted as increased cognitive engagement in the task by sleepy participants (Andreassi, 2007), who showed

impairments in their ability to categorize emotional expressions during the Face Task relative to controls. Sleep restricted participants may have had to exert more effort, via increasing parasympathetic control of heart rate in order to stay focused on the task, which was lengthy (approximately 40 minutes for the Face Task) and somewhat boring, and thus required effort to remain engaged. Heart rate is determined by inputs from both the sympathetic and parasympathetic branches of the nervous system (Berntson, Quigley, & Lozano, 2007); therefore, it is difficult to interpret changes in heart rate in isolation, this could be clarified in future research by incorporating a measure of sympathetic nervous system activity, such as pre-ejection period, which would assist in interpretation of changes in heart rate.

Predicting Performance with Cardiac Measures

Having established that one night of sleep restriction led to the expected changes in mood and performance, and having established RSA as a stable measure within subjects, the main focus of the thesis was to examine cardiac predictors of individual differences in performance vulnerability.

Psychomotor Vigilance Task. Cardiac measures were first explored as predictors of performance on a simple reaction time task. Research has shown relations between higher RSA and performance vary depending on the type of task (i.e. the degree of executive control required), as well as motivational factors (Luque et al., 2016; Capuana et al., 2014; Hansen, Johnsen, & Thayer, 2008). There were no specific predictions made about the role of RSA in performance of this simple reaction time task that involves

sustained attention, and it was explored mainly for comparison to tasks involving emotion processing.

Analysis showed that cardiac measures accounted for variability in performance on the PVT task between sleep restriction and control groups. Sleep restricted participants with moderate to high RSA at baseline (orientation) had slower mean response times on the PVT; sleep restricted participants with lower heart rate at baseline (orientation) demonstrated slower responses relative to control participants when examining a subset of slowest responses on the PVT (10% slow). In consideration of the effects of RSA and heart rate on task performance, it is necessary to consider that RSA is derived from beat-to-beat variability in heart rate; higher RSA and lower relative heart rate both are consistent with increased parasympathetic influence on the heart. Associations between high baseline RSA and slower reaction time are somewhat counter-intuitive, as RSA is typically associated with attentional control (Thayer & Lane, 2000). Spangler, Bell, and Deater-Deckard (2016) suggest that high resting RSA may be associated with poor performance when emotion regulation demands are high, reducing available resources for cognitive task performance. Therefore participants with high baseline RSA may have engaged in more active, effortful self-regulation, resulting in fewer available resources for the PVT; alternatively, slower response times in the sleep restriction group may be an indicator of effective management of fatigue resulting in more deliberate, less impulsive responses to the task.

Predicting Emotion Processing with Cardiac Measures

The primary hypothesis put forward was that RSA would predict vulnerability to performance deficits on emotion processing tasks as a consequence of sleep loss. Higher RSA was expected to be associated with higher accuracy and faster RT to emotion processing tasks in sleep restricted participants in line with previous research relating high HRV to the ability to shift attention away from emotional material in order to maintain performance in terms of response time to a task (Krypotos et al., 2011). It was also expected that higher RSA would be associated with less impairment of neural responses to emotional stimuli quantified by ERP responses. As well, it predicted that high RSA would be associated with better performance at identification of emotion in facial expressions when the emotion was displayed at subtle levels of intensity.

Face Task. There was no support for the hypothesis regarding the intensity of emotional expression at which participants could reliably identify emotion in the face stimuli; no group differences were found on this measure. Lower heart rate during the Face Task was associated with slower response time to sad faces in sleep restriction and the opposite—faster response time to sad faces—in controls. This finding mirrors that reported for the simple reaction time task, where lower baseline heart rate was related to longer response time in the sleep restriction group and faster response time in the control group, and is evidence for differential physiological response associated with sleep loss. Lower heart rate during the task may be reflective of lower engagement or a lack of motivation to perform well in sleep restricted participants—in contrast to increased heart rate, which might reflect increased autonomic arousal (Andreassi, 2007). The moderation model was specific to sad faces, which were notable for impairments in behavioural

(lower accuracy) and enhanced N170 response in the sleep restriction group. This finding might best be interpreted as further evidence of difficulty processing and responding to sad faces relative to other emotional expressions in sleepy participants.

The N170 ERP was larger in response to emotional faces in sleep restriction relative to controls. RSA at baseline moderated the effect of sleep restriction on N170 amplitude, such that those with lower RSA at baseline showed enhanced N170 in response to face stimuli. There was no effect of RSA on N170 amplitude in control participants, suggesting that baseline differences in processing do not account for the enhanced N170 in low RSA participants who were randomly assigned to the sleep restriction group. Moderation analyses indicate that the effect of sleep loss on the N170 is present for those with low relative RSA at baseline, providing support for the role of RSA as a predictor of individual differences in vulnerability to sleep loss. A larger N170 was present for sleep restricted participants with low RSA for all emotions examined (happy, sad, fearful, angry); it is noteworthy that the moderation effect was least powerful with respect to sad faces. This was unexpected in light of the impact of the sleep restriction on behavioural outcomes to sad faces (i.e., impaired accuracy) and the large amplitude difference found in the N170 to sad faces (i.e., larger N170 in SR group). This suggests that there is something different about the way sad faces are processed relative to happy, angry, and fearful faces. RSA at baseline provides insight into vulnerability to sleep deprivation, however, the relationship between RSA, sleep loss, and performance needs further investigation. These results support previous findings that processing of sad faces is particularly impacted by sleep loss (Cote et al., 2014).

IAPS Task. RSA during the IAPS Emotional Picture Task moderated the relationship between group and response time to negative stimuli. Regression models predicting response time to Neutral and Positive stimuli by group including RSA during the task as a moderator were significant overall; however, the moderation effect of task RSA was a trend for Positive and non-significant for Neutral stimuli. Higher task RSA was associated with longer response time in the Control group for Negative stimuli and to a lesser extent with Positive stimuli. In the absence of an effect of group by emotion on response time, these results suggest differential responding by sleep restricted and control participants in order to achieve similar success on the behavioural (identify the emotion) task. For control participants, higher task RSA may be an indicator of increased activation of the parasympathetic nervous system, which would result in increased input from attention regulation systems to focus attention on the categorization task rather than responding to the content of the highly arousing negative picture set. The association with longer response time could be interpreted as more deliberate and less impulsive responding to the stimuli. In the sleep restriction group, the absence of the moderation effect of task RSA on response time to emotional stimuli suggests less effective use of this regulatory strategy, although maintenance of response time values comparable to those shown by controls suggests that sleep restricted participants were able to engage compensatory strategies to maintain performance.

Previous research on ERP responses to an IAPS Affective Picture Task revealed associations between higher HRV and larger LPP to emotional pictures (Dufey et al., 2011). These authors interpreted their findings as suggestive of differential strategies for emotion processing resulting in more accurate stimulus discrimination amongst

individuals with high vagal tone compared to low vagal tone. In the current study, there were no differences in rested control subjects with high or low RSA in terms of LPP response to emotional pictures. However, RSA at baseline moderated the relationship between group and the enhanced LPP to Positive (relative to Neutral) pictures. Sleep restricted participants with low baseline RSA were shown to have a tendency towards larger Positive-Neutral LPP difference score, compared to sleep restricted subjects with high RSA at baseline or control subjects with high or low RSA.

Taken together, these two emotional processing tasks provide evidence that low basal RSA predicts individual differences in vulnerability to sleep loss. Theoretically, it is important to explore individual differences in vulnerability to sleep loss in order to begin to understand how, for whom, and when different degrees of sleep loss impact emotion processing. A better understanding of individual differences could bring together otherwise contrasting findings, such as instances of enhanced or blunted emotional responding related to sleep loss.

Predicting Emotion Processing with Measures of Cardiac Functioning and Affective Style

Emotion Processing, as quantified by the ERP response to the Emotional Face Task, was affected by sleep restriction. RSA moderated the relationship between emotion processing and sleep restriction, showing increased vulnerability to sleep restriction among participants with low RSA at baseline. Measures of affective style were explored in an effort to further identify individual difference factors that might indicate resilience or vulnerability to sleep loss.

Suppression and reappraisal are measures of affective style that are thought to reflect independent strategies for emotion regulation, and can be indexed via the Emotion Regulation Questionnaire (ERQ), developed by Gross and John (2003). The authors described suppression as a coping strategy wherein an emotional response is minimized after it is experienced; this style of responding is related to decreased positive and negative affect and feelings of discomfort due to mismatch between the internal emotional response and external presentation. Reappraisal has been described as a strategy that regulates emotional responding at early stages, and throughout an emotional experience; reappraisal has been associated with positive outcomes such as improved interpersonal relations and increased experience of positive affect. Both suppression and reappraisal have been described as processes requiring cognitive effort; and both result in perceptions that emotional responses were successfully managed.

A tendency towards less habitual use of suppression to regulate emotions in the sleep restriction group was associated with larger N170 ERP response to face stimuli. The association was significant to happy, sad, and fearful faces, and was weaker (a trend) in response to angry faces. In the control group, use of suppression was not related to the N170 response to emotional faces; sleep restricted participants who reported more habitual use of suppression demonstrated responses to emotional faces that were similar to control participants. This suggests that in the sleep restriction group, low habitual suppressors had more difficulty modulating their response to emotional material presented during the Face Task, although this strategy was less effective for threat-relevant stimuli (angry faces). Previous research has related decreased activation of dmPFC in those who habitually use suppression when they were asked to use cognitive

reappraisal strategies, suggesting poor downregulation of amygdala activation by the dmPFC for those with high suppression scores on the ERQ (Che, Luo, Fitzgibbon, & Yang, 2015). Taken with the present research, it is possible that low habitual suppressors were vulnerable to the effects of the sleep restriction, as they were more impaired by decreases in dmPFC connectivity with structures such as the amygdala due to the sleep manipulation, whereas habitual suppressors for whom connectivity may have been reduced prior to the sleep restriction would feel less impacted by the sleep manipulation. More research is needed to clarify these associations.

Habitual use of reappraisal (independent of suppression) was associated with larger N170 ERP response to emotional faces for sleep restricted participants who also demonstrated lower RSA at baseline. This suggests that among participants who are more vulnerable to sleep restriction (i.e., low RSA group), use of reappraisal was related to more attention capture in response to emotional stimuli. It could be postulated that high habitual reappraisers became more engaged with emotional stimuli in order to engage in active methods of emotion regulation when faced with emotional material. In contrast, after a single night of sleep deprivation, low habitual use of reappraisal was associated with vulnerability to sleep loss associated with hyper-focus on negative affective pictures (Cote et al., 2015); taken together, these findings suggest that individual differences in vulnerability to sleep deprivation with respect to emotion processing must be considered in the context of the amount of sleep loss and emotion regulation style.

Habitual (high) suppressors were able to moderate responses to emotional faces after sleep restriction; habitual (high) reappraisers who were vulnerable to sleep restriction (low baseline RSA) engaged in more effortful processing of emotional face

stimuli. This suggests that emotion regulation style has implications for individual differences in response to sleep loss, particularly in conjunction with other factors that convey vulnerability to sleep loss.

Contributions of the Current Study

This study contributes to research on the effects of sleep loss on performance, attention, and emotion. In line with the research agenda set forth by Beattie and colleagues (2015), the present study utilized multiple measures of emotional functioning including subjective (self-report mood), behavioural (accuracy and RT to tasks), and physiological (ERPs, HR and RSA) measures. Individual differences in vulnerability to sleep loss via impairment in emotional processing were evaluated through self-reported affective style measures as well as physiological (RSA) measures. RSA was identified as a predictor of individual differences in response to sleep loss due to its associations with pre-frontal control of cognition, attention, emotion regulation (Thayer & Lane, 2000). The study utilized a commonly experienced degree of sleep loss, increasing applicability of results to the general population.

Overall the study demonstrated that a subtle degree of sleep restriction was sufficient to impact performance, attention, and emotion: Sleep restriction was associated with decreased positive affect, difficulty identifying sad and angry facial expressions, differential neural processing of emotional faces (increased ERP response to happy and sad faces in SR), and a failure to modulate attention to positive emotional pictures. RSA, as a trait-like measure of adaptive functioning and responsiveness to environmental demands, moderated the effects of sleep restriction on emotional processing; low baseline

RSA was associated with differential ERP responses to emotional stimuli in the sleep restriction group. Further, emotion regulation style (suppression, reappraisal) moderated the effect of sleep restriction on emotional processing. Individual differences in RSA and emotion regulation style were shown to predict vulnerability to the effects of sleep loss.

There are a wide range of implications to be drawn from this evidence that a subtle degree of sleep restriction impacts multiple measures of performance and subjective mood states. When sleep loss is unavoidable (e.g., shift workers, new parents) efforts can be made to learn to compensate and adjust for predictable consequences of that loss. It is particularly relevant to consider the implications of these findings for individuals who work with vulnerable populations, such as health care professionals, who often find their sleep curtailed by the demands of shift work. In terms of facial expressions, it would be appropriate to consider health care workers who care for non-verbal individuals, for whom subtleties of expression take on increased importance. It is also necessary to consider the implications of the present research for individuals at-risk for development or relapse of affective disorders; for instance an individual who is more attentive to sad faces after a poor night's sleep, might interpret the world as a more hostile, lonely place, increasing feelings of depression. A recent meta-analysis cited evidence that individuals with insomnia, but without depression, are twice as likely to develop depression compared to those without insomnia (Baglioni et al., 2011). Therapeutic interventions for both affective and sleep disorders should emphasize the relations between sleep loss and emotion in order to improve coping skills and ameliorate the effects of sleep loss in vulnerable populations. Other therapeutic implications include the importance of developing effective emotion regulation styles, as well as consideration

of physiological biofeedback to increase HRV (Miu et al., 2009; Peira, Fredrikson, & Pourtois, 2014).

Future Directions and Limitations of the Current Study

The age range of participants in the current study was limited (age 17-30) and the sample was comprised of a healthy group of college, undergraduate, and graduate students. Although it is useful to establish relations between sleep loss and emotion processing in healthy, young adults, it is necessary to extend these results to younger and older populations for whom sleep characteristics and cardiac functioning would be expected to differ as a function of age (Antelmi et al., 2004; Magee, Iverson, & Caputi, 2013; Umetani, Singer, McCraty, & Atkinson, 1998). Older adults and adolescents may utilize different coping mechanisms, and there may be developmental factors in how sleep and emotion processing interact. It would be useful to compare the impact of a specific degree of sleep loss, such as a single night restricted to four hours, in adolescents, adults, and older adults. A further step would be to compare healthy populations to age-matched clinical populations particularly with respect to psychiatric disorders that are highly comorbid with sleep disorders (e.g., depression).

Data regarding the amount and quality of sleep obtained by participants both leading up to and during the sleep restriction was dependent on a combination of self-report (diaries) and actigraphy monitoring. Although useful in confirming sleep times, actigraphy reports could be ambiguous (i.e., difficult to discriminate between periods of inactivity such as watching a movie and sleep), and do not provide detailed information about sleep architecture that would be obtained with overnight polysomnography.

However, there were also benefits to the study design in terms of participants sleeping at home. For example time spent in the laboratory environment was equivalent for both groups, and sleep was naturalistic in the home environment.

Further exploration of factors that account for individual differences in sleep loss are important for future research, the role of RSA as a trait-like individual difference measure associated with resiliency and vulnerability should be further explored in connection with sleep loss. RSA is a highly accessible physiological measure, which can be recorded both in laboratory and naturalistic settings, which makes it a versatile measure. Perhaps in studies using more nights of sleep restriction, RSA will prove to be a more robust predictor of individual differences to sleep loss through the increased variability on performance measures that would emerge in a chronic sleep restriction paradigm (Van Dongen et al., 2003). In terms of study design, the format of the experimental day in the current study was such that the first block of stimulus presentation during tasks was not ideal for analysis of the ECG. Due to concerns about postural change just prior to task onset, ECG was selected from the second block of stimulus presentation, ensuring stable, seated posture for 5 minutes. It has been suggested cardiac measures may show habituation effects (Andreassi, 2007), and effects of time on task (Luque-Casado, Perales, Cardenas, & Sanabria, 2016), suggesting the timing of task ECG data analysed in the current study was not ideal, and may have masked ECG reactivity effects.

Future research should consider possible differences due to time of night on the sleep restriction period. Early night sleep has been shown to be rich in slow wave sleep, while late night sleep has been shown to be rich in REM sleep. There is some evidence

that the characteristics of the sleep obtained in a sleep restriction paradigm can affect outcomes on emotional processing tasks (Wagner, Fischer, & Born, 2002). Additionally, movement from a single night to multiple nights, or different degrees of sleep restriction would be informative as to the trajectory of changes in emotion processing related to sleep loss. The addition and development of measures of emotion processing that approximate interpersonal interactions would provide more ecological validity for the implications of changes in emotion processing due to sleep loss.

Despite these limitations, the present study was able to bring together multiple measures of behavioural and psychophysiological functioning in response to a naturalistic degree of sleep restriction in a healthy, young adult sample. The outcomes of the research confirm the importance of sleep for emotional functioning and have numerous implications for daily functioning in healthy, at-risk, and clinical populations.

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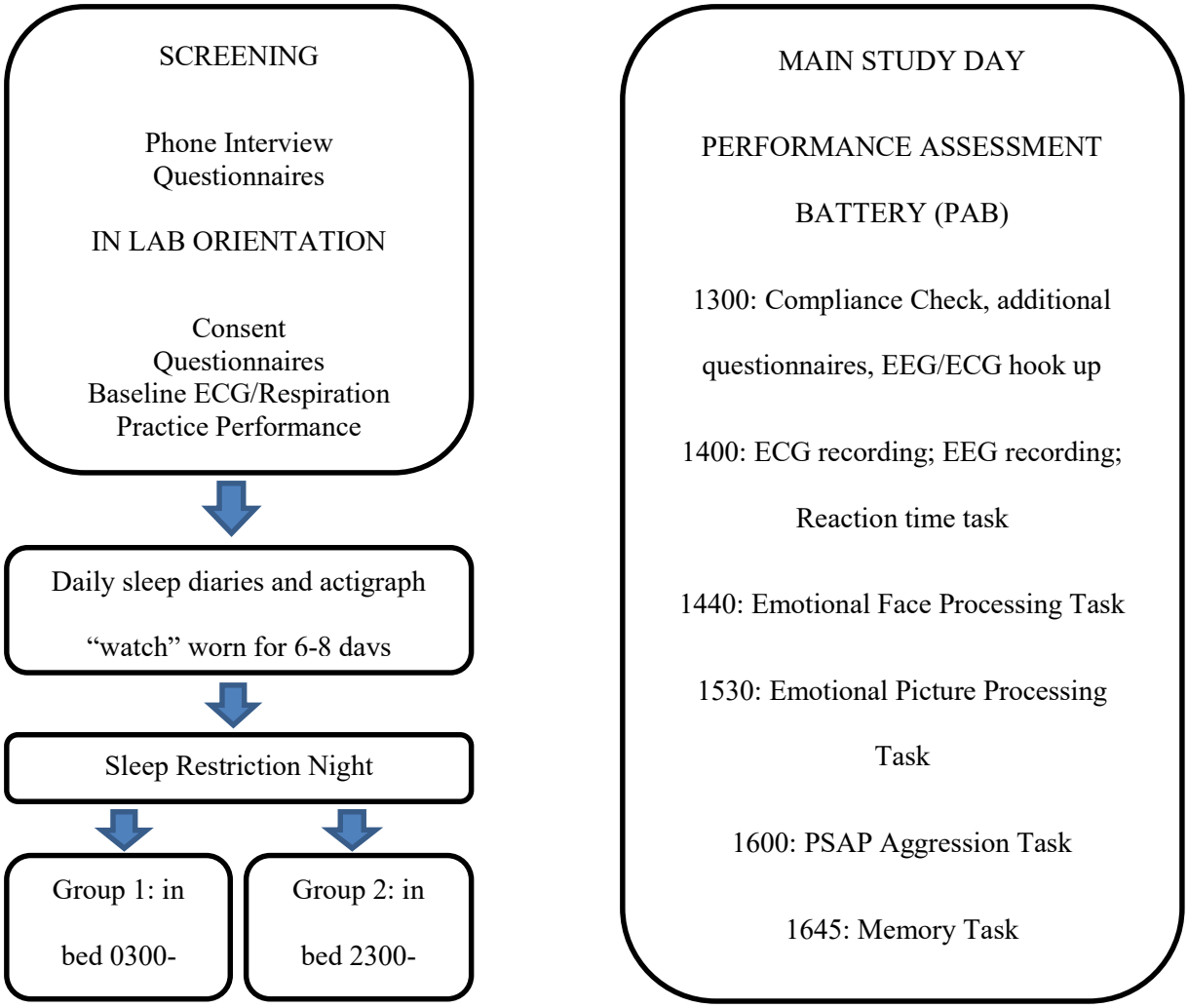
Appendix A

Study Protocol



Study participants are screened via a scripted phone interview, after which more detailed screening information is obtained through self-report questionnaires. An orientation session is scheduled in the sleep laboratory where detailed information regarding study participation is provided and consent is obtained. During the orientation session a resting ECG and respiration recording is obtained, after which participants are introduced to the face and picture processing tasks that they will complete during the PAB. Participants are provided with online or paper sleep diaries to complete for one week (6-8 days) prior to returning to the laboratory for the PAB, and an activity monitor to wear during that time frame. Participants are randomly assigned to Group 1 or Group 2 on the day prior to their scheduled attendance in the lab. All participants arrive at the sleep laboratory at 1300, when activity monitors are checked against sleep diary entries and additional questionnaires are completed before electrode caps are put on. A resting ECG is obtained and measures of physiological alertness (EEG recording) and psychomotor vigilance (reaction time) are obtained. Participants are given a 10 minute break before the face processing task, emotional picture processing task, aggression task and the memory task.

Appendix B

IAPS Stimuli Data

	Negative							Neutral							Positive					
Block	IAPS Ref. No.	Description	Mean Valence Rating	Valence SD	Mean Arousal Rating	Arousal SD	Block	IAPS Ref. No.	Description	Mean Valence Rating	Valence SD	Mean Arousal Rating	Arousal SD	Block	IAPS Ref. No.	Description	Mean Valence Rating	Valence SD	Mean Arousal Rating	Arousal SD
1	6312	Abduction	2.48	1.52	6.37	2.30	1	7185	AbstractArt	4.97	0.87	2.64	2.04	1	2070	Baby	8.17	1.46	4.51	2.74
1	6200	AimedGun	3.20	1.62	5.82	1.99	1	5395	Boat	5.34	1.21	4.23	2.03	1	2391	Boy	7.11	1.77	4.63	2.43
1	6243	AimedGun	2.33	1.49	5.99	2.23	1	7090	Book	5.19	1.46	2.61	2.03	1	1604	Butterfly	7.11	1.41	3.30	2.17
1	2100	AngryFace	3.85	1.99	4.53	2.57	1	7546	Bridge	5.40	1.13	3.72	2.16	1	2345	Children	7.41	1.72	5.42	2.47
1	6350	Attack	1.90	1.29	7.29	1.87	1	7052	Clothespins	5.33	1.32	3.01	2.02	1	2165	Father	7.63	1.48	4.55	2.55
1	6571	CarTheft	2.85	2.05	5.59	2.50	1	7040	DustPan	4.69	1.09	2.69	1.93	1	7508	FerrisWheel	7.02	1.46	5.09	2.11
1	6311	DistressedFem	2.58	1.56	4.95	2.27	1	7030	Iron	4.69	1.04	2.99	2.09	1	1460	Kitten	8.21	1.21	4.31	2.63
1	2710	DrugAddict	2.52	1.69	5.46	2.29	1	7175	Lamp	4.87	1.00	1.72	1.26	1	2311	Mother	7.54	1.37	4.42	2.28
1	9560	DuckInOil	2.12	1.93	5.50	2.52	1	7035	Mug	4.98	0.96	2.66	1.82	1	5780	Nature	7.52	1.45	3.75	2.54
1	2799	Funeral	2.42	1.41	5.02	1.99	1	2102	NeuMan	5.16	0.96	3.03	1.87	1	1710	Puppies	8.34	1.12	5.41	2.34
1	2352.2	bloodykiss	2.09	1.5	6.25	2.1	1	7233	Plate	5.09	1.46	2.77	1.92	1	1610	Rabbit	7.82	1.34	3.08	2.19
1	1300	PitBull	3.55	1.78	6.79	1.84	1	2383	Secretary	4.72	1.36	3.41	1.83	1	4640	Romance	7.18	1.97	5.52	2.28
1	9341	Pollution	3.38	1.89	4.50	2.10	1	7038	Shoes	4.82	1.20	3.01	1.96	1	4641	Romance	7.20	1.59	5.43	2.10
1	1270	Roach	3.68	1.85	4.77	2.44	1	7004	Spoon	5.04	0.60	2.00	1.66	1	5594	Sky	7.39	1.45	4.15	2.76
1	2455	SadGirls	2.96	1.79	4.46	2.12	1	7130	Truck	4.77	1.03	3.35	1.90	1	5830	Sunset	8.00	1.48	4.92	2.65
1	1050	Snake	3.46	2.15	6.87	1.68	2	7186	AbstractArt	4.63	1.60	3.60	2.36	1	8350	TennisPlayer	7.18	1.56	5.18	2.28
1	6212	Soldier	2.19	1.49	6.01	2.44	2	7010	Basket	4.94	1.07	1.76	1.48	1	7260	Torte	7.21	1.66	5.11	2.19
1	1201	Spider	3.55	1.88	6.36	2.11	2	7041	Baskets	4.99	1.12	2.60	1.78	1	8496	WaterSlide	7.58	1.63	5.79	2.26
1	2095	Toddler	1.79	1.18	5.25	2.34	2	7547	Bridge	5.21	0.96	3.18	2.01	1	4626	Wedding	7.60	1.66	5.78	2.42
1	2683	War	2.62	1.78	6.21	2.15	2	7140	Bus	5.50	1.42	2.92	2.38	1	5623	Windsurfers	7.19	1.44	5.67	2.32
2	6260	AimedGun	2.44	1.54	6.93	1.93	2	7217	ClothesRack	4.82	0.99	2.43	1.64	2	5460	Astronaut	7.33	1.51	5.87	2.50
2	2120	AngryFace	3.34	1.91	5.18	2.52	2	2396	Couple	4.91	1.05	3.34	1.83	2	8380	Athletes	7.56	1.55	5.74	2.32
2	6510	Attack	2.46	1.58	6.96	2.09	2	7080	Fork	5.27	1.09	2.32	1.84	2	2398	Boat	7.48	1.32	4.74	2.11
2	6550	Attack	2.73	2.38	7.09	1.98	2	7055	Lightbulb	4.90	0.64	3.02	1.83	2	8210	Boat	7.53	1.31	5.94	2.07
2	6315	BeatenFem	2.31	1.69	6.38	2.39	2	7009	Mug	4.93	1.00	3.01	1.97	2	2222	BoysReading	7.11	1.54	4.08	2.15
2	9000	Cemetery	2.55	1.55	4.06	2.25	2	2214	NeutMan	5.01	1.12	3.46	1.97	2	1540	Cat	7.15	1.96	4.54	2.35
2	2981	DeerHead	2.76	1.94	5.97	2.12	2	6150	Outlet	5.08	1.17	3.22	2.02	2	2216	Children	7.57	1.31	5.83	2.20
2	1301	Dog	3.70	1.66	5.77	2.18	2	7025	Stool	4.63	1.17	2.71	2.20	2	2341	Children	7.38	1.59	4.11	2.31
2	2717	DrugAddict	2.58	1.32	5.70	2.16	2	7950	Tissue	4.94	1.21	2.28	1.81	2	7580	Desert	7.51	1.60	4.59	2.72
2	2276	Girl	2.67	1.66	4.63	1.93	2	7037	Trains	4.81	1.12	3.71	2.08	2	2340	Family	8.03	1.26	4.90	2.20
2	2811	Gun	2.17	1.38	6.90	2.22	3	7187	AbstractArt	5.07	1.02	2.30	1.75	2	2395	Family	7.49	1.69	4.19	2.40
2	3220	Hospital	2.49	1.29	5.52	1.86	3	7006	Bowl	4.88	0.99	2.33	1.67	2	2091	Girls	7.68	1.43	4.51	2.28
2	3225	Mutilation	1.82	1.22	5.95	2.46	3	7705	Cabinet	4.77	1.02	2.65	1.88	2	7330	IceCream	7.69	1.84	5.14	2.58
2	6838	Police	2.45	1.44	5.80	2.09	3	7235	Chair	4.96	1.18	2.83	2.00	2	5660	Mountains	7.27	1.59	5.07	2.62
2	1274	Roaches	3.17	1.53	5.39	2.39	3	7057	Coffeecup	5.35	1.37	3.39	2.01	2	1441	PolarBears	7.97	1.28	3.94	2.38
2	2800	SadChild	1.78	1.14	5.49	2.11	3	7020	Fan	4.97	1.04	2.17	1.71	2	1920	Porpoise	7.90	1.48	4.27	2.53
2	9280	Smoke	2.80	1.54	4.26	2.44	3	7100	FireHydrant	5.24	1.20	2.89	1.70	2	4614	Romance	7.15	1.44	4.67	2.47
2	1052	Snake	3.50	1.87	6.52	2.23	3	7050	HairDryer	4.93	0.81	2.75	1.80	2	8170	Sailboat	7.63	1.34	6.12	2.30
2	1220	Spider	3.47	1.82	5.57	2.34	3	7059	Keyring	4.93	0.81	2.73	1.88	2	8034	Skier	7.06	1.53	6.30	2.16
2	6213	Terrorist	2.91	1.52	5.86	2.06	3	7550	Office	5.27	1.40	3.95	1.91	2	5260	Waterfall	7.34	1.74	5.71	2.53
3	6230	AimedGun	2.37	1.57	7.35	2.01	3	7000	RollingPin	5.00	0.84	2.42	1.79	3	8540	Athletes	7.48	1.51	5.16	2.37
3	6250	AimedGun	2.83	1.79	6.54	2.61	3	7036	Shipyard	4.88	1.08	3.32	2.04	3	5833	Beach	8.22	1.08	5.71	2.66
3	2110	AngryFace	3.71	1.82	4.53	2.25	3	7031	Shoes	4.52	1.11	2.03	1.51	3	2224	Boys	7.24	1.58	4.85	2.11
3	6360	Attack	2.23	1.73	6.33	2.51	3	7595	Traffic	4.55	1.46	3.77	2.22	3	7400	Candy	7.00	1.64	5.06	2.23
3	6560	Attack	2.16	1.41	6.53	2.42	3	2305	Woman	5.41	1.12	3.63	2.04	3	5551	Clouds	7.31	1.63	3.26	2.47
3	1525	AttackDog	3.09	1.72	6.51	2.25								3	2530	Couple	7.80	1.55	3.99	2.11
3	9001	Cemetery	3.10	2.02	3.67	2.30								3	2332	Family	7.64	1.60	4.30	2.29
3	2900	CryingBoy	2.45	1.42	5.09	2.15								3	5480	Fireworks	7.53	1.63	5.48	2.35
3	2751	DrunkDriving	2.67	1.87	5.18	2.39								3	8461	HappyTeens	7.22	1.53	4.69	2.20
3	6821	Gang	2.38	1.72	6.29	2.02								3	1590	Horse	7.18	1.64	4.74	2.13
3	9290	Garbage	2.88	1.52	4.40	2.11								3	1463	Kittens	7.45	1.76	4.79	2.19
3	6830	Guns	2.82	1.81	6.21	2.23								3	2540	Mother	7.63	1.51	3.97	2.33
3	2205	Hospital	1.95	1.58	4.53	2.23								3	5700	Mountains	7.61	1.46	5.68	2.33
3	3550	Injury	2.54	1.60	5.92	2.13								3	8370	Rafting	7.77	1.29	6.73	2.24
3	1275	Roaches	3.30	1.65	4.81	2.22								3	8499	Rollercoaster	7.63	1.41	6.07	2.31
3	2703	SadChildren	1.91	1.26	5.78	2.25								3	4623	Romance	7.13	1.80	5.44	2.23
3	9561	SickKitty	2.68	1.92	4.79	2.29								3	5831	Seagulls	7.63	1.15	4.43	2.49
3	1111	Snakes	3.25	1.64	5.20	2.25								3	8510	SportCar	7.32	1.72	4.93	2.56
3	1205	Spider	3.65	1.76	5.79	2.18								3	1620	Sprgbok	7.37	1.56	3.54	2.34
3	6570	Suicide	2.19	1.72	6.24	2.16								3	7325	Watermelon	7.06	1.65	3.55	2.07

Appendix C

Ethics Clearance Form

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE: October 28, 2013

PRINCIPAL INVESTIGATOR: COTE, Kimberly - Psychology
FILE: 12-174 - COTE

TYPE: Faculty Research STUDENT: Kevin MacDonald
SUPERVISOR: Kimberly Cote

TITLE: The impact of sleep restriction on attention, memory, and emotion

ETHICS CLEARANCE GRANTED

Type of Clearance: MODIFICATION Expiry Date: 3/31/2014

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from **10/28/2013** to **3/31/2014**.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before **3/31/2014**. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

Brian Roy, Chair
Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

Appendix D

Telephone Interview Script
Sleep Restriction 2013 Study (updated 2014)

I. DESCRIBE STUDY:
We are interested studying the effects of sleep loss on attention and emotion. In this study, some people will be asked to restrict their sleep to 4 hours on one night, while others will be asked to sleep for 8 hours. Participants will then be asked to spend one afternoon in the Sleep Research Laboratory where EEG will be recorded to measure brain activity while performing various computer tasks of attention and emotion.

Here are the details of what would be expected of you:

1. First, we will get some information from you on the phone today to see if you meet our basic criteria for participation.

2. **If you are suitable for the study,** we will then ask you to attend a 1 1/2-hr ORIENTATION session where you will tour the Sleep Lab, and be given a full consent form – this provides details about the study – and you can decide whether or not you are interested in full participation at that time. You will then complete a series of questionnaires, have your heart rate recorded, and practice the computerized cognitive tasks that we will use in the main study. The questionnaires will ask questions about your physical and mental health, sleep habits and personality. These questionnaires will confirm that you meet all of the eligibility requirements for this study.
3. **If you wish to participate**, you will then be asked to complete a sleep/wake diary from home each morning and wear an Activity Monitor (that looks like a wrist watch) for a period of one week prior to participation in the study. You will be asked to keep a regular sleep/wake schedule that week, sleeping for about 8 hrs each night from approximately 11pm-7am (or midnight-8am).

If you are deemed ineligible or if you choose not to participate in the laboratory study, there will be no compensation for the pre-study screening (that is, the orientation session, and sleep diaries/activity monitor for the week prior to the main study day). If you do not complete the main part of the study for whatever reason, all of the information you provided in pre-study screening will be destroyed.

4. **For the main part of the study**, you will be scheduled to spend one afternoon in the Sleep Laboratory, from 1-6pm for a performance assessment. You will have your brain activity recorded using an electrode cap while performing computer tasks. You will also be asked to provide saliva samples at various times by spitting into a test tube because we are measuring hormones. Also, you may or may not be asked to restrict your sleep on the prior night.

For *complete* participation, you will be given a $50 honorarium.

Are you interested? [yes] – Ok, I have a few questions for you to make sure you are suitable for the study. If you are the type of person we are looking for, we will schedule your orientation appointment.

Date:	**ID CODE**:

II. INCLUSION CRITERIA:
First, do you think you would have any difficulty keeping a regular sleep schedule for the one week before the lab study, that is, sleeping about 8 hrs each night and going to bed from about 11pm-7am or midnight-8am (i.e., not staying up really late or sleeping in on any of the days for a week)? -

_____

What days would you be free to participate from about 1-6pm (indicate schedule):

_____

Age (17-30): _____
Weight (indicate kg or lbs): _____
Gender: M / F

If female - do you have a "regular" menstrual cycle, and do you take any hormones for contraceptive purposes or to regulate your cycle (e.g., birth control pills, patches or injections)? [yes regular; no use of hormones - Must have not used for 2 months and now have regular cycle]: _____

Smoker: Y / N [no]
Handedness: R / L [right]
How many caffeinated drinks do you typically have in a day [min - moderate, <3]: ____
Is English your first language (if not, did you learn before age 8 or describe fluency): ___
Do you have any difficulties with vision [OK with glasses/contacts], or hearing [no, in both ears]: _____

III. Questions on SLEEP:
1. Do you consider yourself to be a good sleeper? [yes]: _____
2. What are your usual sleeping times [approx 23:00-07:00]:_____
3. How does this change on weekends? [sleeping-in a bit is ok] _____
4. Do you have difficulty *falling* asleep at night [no]: _____
5. Do you *wake up* often during the night and are unable to return to sleep [no]:_____
6. Have you ever been diagnosed with a Sleep Disorder [no]:_____
7. Have you ever been told you kick your legs all-night long or stop breathing during the night? [no] _____
8. Do you experience restless legs or a "creepy crawling" sensation before bed each night? [no] _____
9. Would you describe yourself as *excessively* tired during the day [no]: _____
10. Do you currently work shift work [no]; any history of shiftwork? _____
11. Do you take daytime naps? Y / N
How frequently (# / week) _____ Duration for each _____
12. Have you ever pulled an all-nighter? How often/how many times etc?

IV. Questions on HEALTH:
1. Are you presently in good health [yes]: _____
2. Taking any medications [no]: _____
3. Any history of depression, anxiety or schizophrenia [no]:_____
4. Any history of head injury (e.g., car accident, stroke, loss of consciousness), epilepsy, or other neurological condition [no]: _____
5. Any history of chronic pain [no]: _____
6. Any history of heart disease or cardiac abnormalities [no]: _____

Appendix E

LETTER OF INFORMATION / CONSENT FORM

BROCK UNIVERSITY SLEEP RESEARCH LABORATORY
PSYCHOLOGY DEPARTMENT

Title of Study: Impact of Sleep Restriction on Attention and Emotion
Principal Investigator: Kimberly A. Cote, Ph.D.
Co-investigator: Cheryl McCormick, PhD

This letter of information/consent form is provided to you for your information on the website of the Brock University Sleep Research Laboratory. You should carefully read this form to understand all aspects of participation in the research study prior to completing the on-line eligibility questionnaires. By completing the on-line questionnaires, you are acknowledging that you have read and understood this form and you are providing consent to participate in the full research study. You will be asked to sign this form and be given a copy during your next visit to the Sleep Laboratory.

If you have questions about the details of this study prior to completing the on-line questionnaires, please call the Sleep Laboratory at 905-688-5550, ext.3795.

Name of Participant:_____
(*Please print your name in the space above*)

PART A: INFORMATION ABOUT THE STUDY

I understand that I am being invited to participate in a research study investigating alertness, attention, and emotion following one night of sleep restriction. This study will be of benefit to me because I will be able to learn about the impact of sleep loss on performance; as well, it will inform the scientific community about the impact of sleep loss on waking brain function.

I understand that participation has four phases:

5. Pre-study screening by telephone;
6. A 1.5-hr orientation session in the Sleep Lab, where I will tour the facilities, complete questionnaires, have heart rate monitored, and practice the computerized cognitive tasks that will be used in the main study;
7. Completion of a sleep/wake diary from home each morning and wearing an Activity Monitor (that looks like a wrist watch) for a period of one week at home prior to participation in the main study;

8. Spending one afternoon in the Sleep Laboratory, from 1pm-6pm, for performance assessment following a night on which my sleep may or may not have been restricted.

Screening questionnaires will ask questions about physical and mental health, sleep habits, and personality. If responses or scores on these questionnaires raise concerns about mental health, you will be contacted and given information about available resources for counselling at the Student Development Center.

During the phase 3, I understand that I must wear an Activity Monitor on my left-wrist at all times (except when showering, doing dishes, or swimming because it's not waterproof) and that I must complete the daily sleep/wake diary on-line within 30 minutes of awakening each day. The sleep diary is available at: http://www.brocku.ca/sleeplab/sleeplab.php or can be completed on paper. I understand that I must keep a regular sleep/wake schedule during this week, retiring for bed and getting out of bed at the same times each day (typically sleeping for at least 8 hours sometime between the approximate hours of 11pm and 8am). I understand that I should not stay up late or sleep in on any days during this week. Further, I understand that I should eat regularly and minimize alcohol intake for the week.

The diary and activity watch data will be examined to verify compliance with instructions to sleep regularly. I understand that there will be no compensation for the pre-study screening described above if I am deemed ineligible to participate or if I choose not to participate in the laboratory study (phase 4 above). If I withdraw or I am withdrawn by experimenters at this part of the study, my information will be destroyed.

Prior to the main study in the Sleep Laboratory (phase 4 above), I understand that I must:

- be in bed between 11pm and 07 am (getting out of bed at 07am sharp) on the prior night
- drink no alcohol on the prior night
- drink no caffeine on the day of the study
- take no naps on the day of the study
- obtain no vigorous exercise on the day of the study

I understand that I will be informed as to whether I am in the **Sleep** group (sleep 8 hrs; time in bed is set at 11pm to 7am) or **Sleep Restriction** group (sleep 4 hours; time in bed is restricted to 3am-7am) by e-mail on the day before the main study, and that I must reply to that e-mail message to verify receipt. I understand that I will also be sent study reminders by email. If assigned to the Sleep Restriction group, I understand that:

- I can expect to feel sleepy on the next day
- I must schedule extra time to sleep on the evening following the laboratory study
- I must not drive to or from the laboratory that day (this is because sleep loss impairs cognitive function including motor ability, response time, and

attention which may lead to an increased risk of accidents while driving, operating machinery, etc). If you live on campus, a research assistant will walk you back to your residence. You are encouraged to arrange someone to drive you to campus and pick you up on this day. If you cannot arrange a ride, a taxi service will be provided.

On the day of the main study, I understand that I must eat breakfast soon after awakening, and eat lunch at 12:00 noon. I must arrive to the Sleep Lab (MC-B416 – 4th floor above Psyc Dept) at 1pm sharp.

During the main study day, I understand that my brain activity will be monitored using an electrode cap, and that additional electrodes will be taped on my face (near eyes, under chin, and on chest) to monitor eye movements, muscle activity and heart rate.

During the main study day, I understand that I will perform a variety of computerized tasks designed to measure processing of emotional faces and picture scenes. In addition, I will play a computerized game of competition that is designed to examine the effects of sleepiness on game playing. Further, I understand that I will complete various surveys to provide subjective information on alertness, mood, and perception of performance.

I understand that I will be asked to provide saliva samples (by spitting into a test tube) at five different times during the study to measure hormones.

PART B: INFORMATION ABOUT STUDY RISKS AND YOUR RIGHTS AS A PARTICIPANT

I understand that I may experience some skin irritation (redness and dry skin) as a result of having electrodes attached to my scalp and face. This is temporary and may be reduced by applying moisturizing cream to the areas where electrodes were placed.

If assigned to the sleep restriction condition, I understand that this level of sleep loss will cause impairments to cognitive function and mood, including motor ability, response time, and decision making. I understand that precaution must therefore be taken; specifically, I should not drive or operate machinery. At the end of the study, I understand that I should return home immediately and plan to get extra sleep that night by planning to go to bed earlier and wake up later. I understand that I should normally feel rested again after one night of sleep, but that I should continue to extend sleep time (by going to bed earlier and getting up later, or by napping) until I feel sufficiently rested to function normally (i.e., feel alert and able to maintain wakefulness throughout the day).

I understand the importance of following the above instruction pertaining to sleep and activities, and that I may be withdrawn from the study for failure to comply with instructions. I understand that there will be no compensation if I am removed from the study for non-compliance.

I understand that the Sleep Laboratory facilities are under 24-hour video surveillance. All activities in the main laboratory, bedrooms, and the kitchen/lounge areas are recorded and stored in the Sleep Laboratory until completion of the study. The videotaped data will not be used in public presentation or advertising.

I understand that I will receive an honorarium or credit for my participation. I will be paid a total of $50 for completion of the full study, or receive 3-hrs course credit (if applicable for one of your Psychology courses). If I withdraw or do not meet study inclusion criteria after the screening procedures (phases 1 - 3), there will be no compensation. I understand that should I withdraw from the study, researchers will destroy any data that I have provided upon request.

I understand that my participation is voluntary and I may withdraw from the study at any time, for any reason, without penalty. I am under no obligation to answer any question or participate in any aspect of this project that I consider invasive, offensive, or inappropriate. I understand that I may ask further questions at any time.

I understand that all personal data will be kept strictly confidential and all information will be coded so that my name is not associated with my answers. Only the researchers named above, and research assistants working under supervision of these researchers, will have access to the data. Data will be kept in the Sleep Research laboratory indefinitely. I understand that I am not anonymous in this study because the nature of the study requires that research assistants interact with each participant in the laboratory on a one-to-one basis and have contact information to schedule appointments.

Your signature below indicates that, you are of the age of legal consent (i.e., 17 years or older), you have read and understood the procedures of the study, and you agree to participate.

Participant's Signature_____ Date _____
(to be signed during your visit to the Sleep Laboratory for orientation)

PART C: CONTACT INFORMATION

This research is funded by the Natural Science and Engineering Research Council (NSERC) of Canada. This study has been reviewed and cleared by the Bioscience Research Ethics Board (File # 12-174). For answers to questions about your rights as a research participant, contact the Research Ethics Officer, at (905) 688-5550 ext. 3035, or reb@brocku.ca.

If you have any questions or concerns about your participation in the study you may contact the Principle Investigator, Dr. Kimberly Cote in the Psychology Department at (905) 688-5550, extension 4806.

No individual feedback from the sleep study or performance data may be provided at any

time. Feedback about the outcome of the study will be available by request after final publication of the data (email: kcote@brocku.ca).

Please take a copy of this form with you for future reference. IF YOU NEED TO CONTACT THE LABORATORY REGARDING YOUR APPOINTMENT OR STUDY PROCEDURES, PLEASE CALL US AT **905-688-5550, EXT. 3795.**

I have fully explained the procedures of this study to the above volunteer.

Researcher's Signature_____ Date _____

Appendix F

Sleep & Activity Diary – Paper version

Brock University Sleep Research Laboratory [905-685-5550, ext. 3795]

- **Instructions:** Please complete this diary each MORNING within 30 minutes after getting out of bed. It is important that you complete the diary first thing in the morning, and at approximately the same time each day.

Participant ID: _____ Today's Date: _____ Time survey was completed: _____

Part 1. Answer the following questions about how you felt **Going to Bed** last night:

1. At what time did you go to bed last night (lights out)? _____

2. How long do you think it took you to fall asleep (minutes)? _____

3. Did you experience any intrusive thoughts or worries when you were lying down to fall asleep? *Circle: Y or N*

If YES-answer 3a and 3b below

a. How frequently did these thoughts, worries, and concerns come to mind as you were trying to fall asleep? *Select a # between 1 and 7 using the key below* _____
   1 - my mind was **free** of thoughts, worries and concerns
   4 - my mind had **some** thoughts, worries, and concerns
   7 - my mind was **filled** with thoughts, worries and concerns

b. How distressing were these thoughts? *Select a # between 1 and 7 using the key* _____
   1 - **not at all** distressing
   4 - **somewhat** distressing
   7 - **very** distressing

4. Were there any unusual circumstances that made it difficult for you to fall asleep? (e.g., noise, temperature, physical symptoms, etc) *Circle: Y or N* If yes, Explain:

_____

5a. How much sleep did you get last night (hours and minutes)? _____
5b. Was this a typical night for you (i.e., a typically good, or typically bad night): *Circle: Y or N*
5c. If the quality of your sleep was not typical, please explain why:

_____
_____

Part 2. Answer the following questions about how you felt **During the Night**:

6. Please rate the quality of your sleep last night, from your ***worst*** possible sleep (1) to your ***best*** possible sleep (7). *Select a # between 1 and 7*_____

7a. How many times did you wake up in the middle of the night? _____
7b. How much time did you spend awake in the middle of the night? (total duration for all awakenings combined) (in minutes)_____

8. Were there any unusual circumstances that kept you awake during the night? (e.g. noise, temperature, physical symptoms, etc) Circle: Y or N If yes, Explain:

_____

Part 3. Answer the following questions about how you felt **Upon Awakening** this morning:

9. At what time did you wake up in the morning (time of last awakening)? _____

10. At what time did you get out of bed in the morning? _____

11. Select the number that best describes how you felt when you got out of bed this morning:

a. Fatigue Scale *Select one choice below* _____

Full of energy: enough to tackle my usual physical activities	1
Energy level is quite high but not at its peak: most physical activities would pose no problem.	2
Energy level is such that one would prefer to be doing very light or sedentary tasks at this point.	3
Energy level is adequate for only routine activities at a leisurely pace.	4
Energy level is such that it would be preferable to rest before doing any routine activity.	5
Energy level is quite low: would strongly prefer to rest rather than do anything else.	6
Totally physically exhausted: unable to undertake the least activity.	7

b. Sleepiness Scale *Select one choice below* _____

Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7

Part 4. Answer the following questions about how you felt **During the Previous Day**:

12. Did you experience any difficulty with daytime functioning yesterday (e.g., trouble paying attention or staying awake in class, studying, getting things done)? *Select a # between 1 and 7 using the key below*

_____

1 - I had no trouble functioning properly
4 - I had some trouble functioning properly
7 - I had a lot of trouble functioning properly

13. How sleepy did you feel yesterday during the daytime? *Select a # between 1 and 7 using the key below*

_____

1 - I did not feel sleepy at all
4 - I felt somewhat sleepy
7 - I felt extremely sleepy

14. Did you nap yesterday? *Circle: Y or N* If YES, indicate total duration for all naps combined (in minutes)_____

15. Please complete the table below to indicate all of your **caffeine** intake (coffee, tea, cola, chocolate), **alcohol** consumption, **medication** use, and **exercise** activity during the previous day. Complete the table in chronological order, from morning to evening intake/activities. *Add as many entries as needed.*

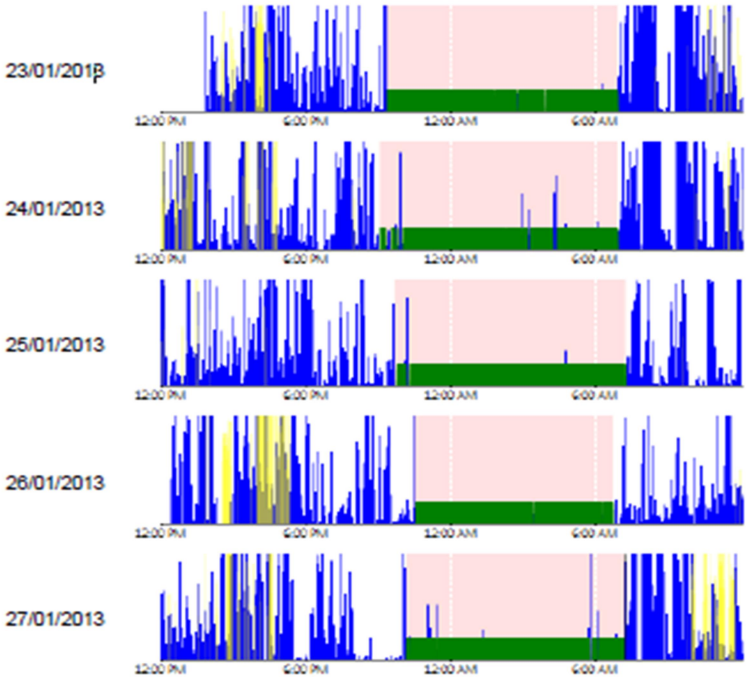
Indicate Category	**Specify type and amount**	**Time of day**
***Example**: Caffeine*	*1 medium Starbuck's coffee*	*08:00 am*
***Example**: Medication*	*1 500 mg Aspirin tab*	*3:00 pm*
***Example**: Exercise*	*1 hr Yoga*	*6:00 pm*

16.Comments_____
_____
_____
_____

Thank-you! Call us if you have any questions (905-688-5550, ext. 3795).

Appendix G

ActiGraph Sleep Report
Name: Elizabeth
Data Start: 23/01/2013 1:45:00 PM
Data End: 27/01/2013 11:54:00 AM
Device Serial: MRA2A29120109

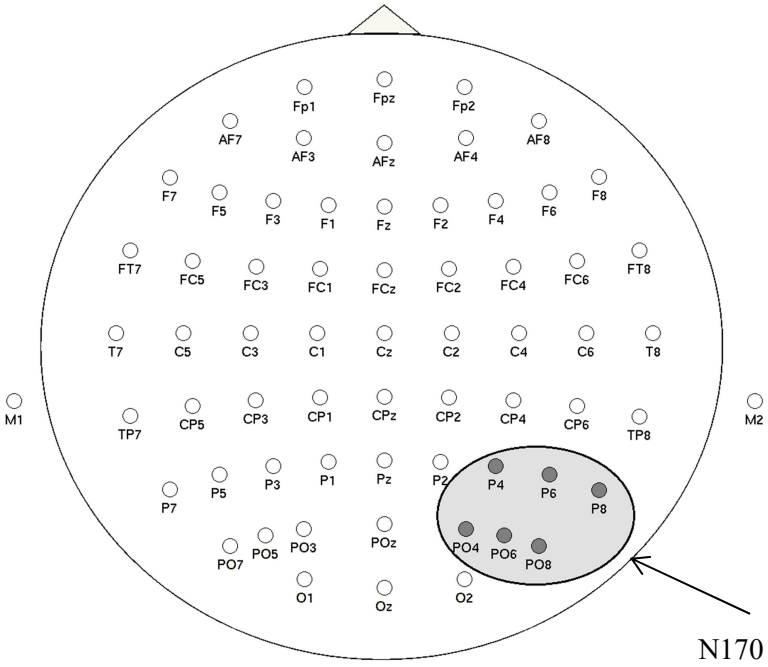


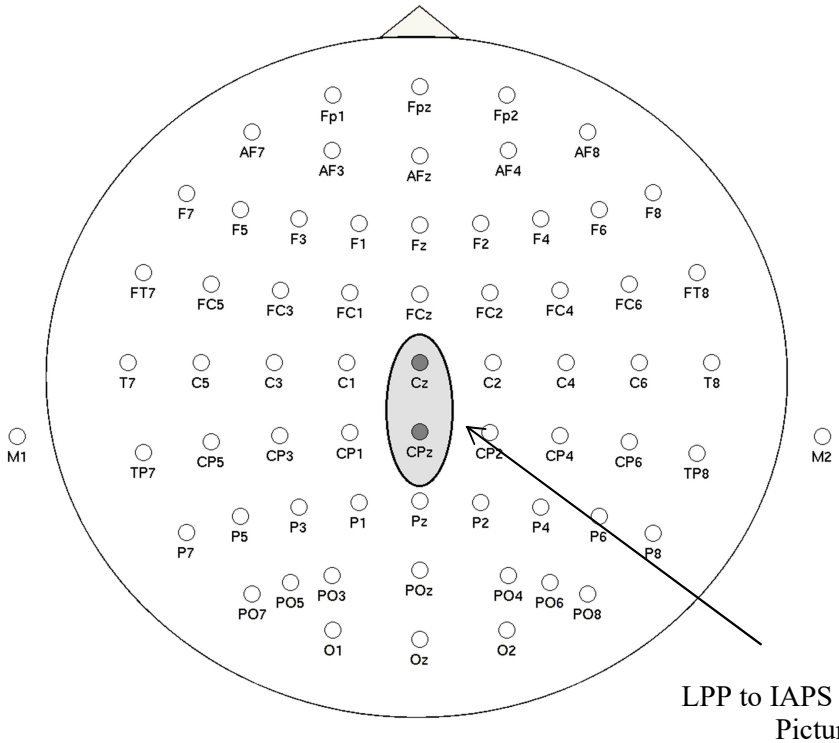
Sleep Period Breakdown
Sleep Algorithm Used: Sadeh

In Bed	Out Bed	Latency (min)	Efficiency	Total Time In Bed (min)	Total Sleep Time (TST) (min)	Wake After Sleep Onset (WASO)	# of Awakenings	Avg Awakening (min)
23/01/2013 9:19 PM	24/01/2013 6:53 AM	4	94.77%	574	544	26	14	2.14
24/01/2013 9:07 PM	25/01/2013 6:53 AM	0	86.52%	586	507	79	24	3.29
25/01/2013 9:41 PM	26/01/2013 7:15 AM	4	94.6%	574	543	27	18	1.72
26/01/2013 10:32 PM	27/01/2013 6:42 AM	3	94.08%	490	461	26	14	2.07
27/01/2013 10:10 PM	28/01/2013 7:10 AM	0	91.48%	540	494	46	21	2.19

Appendix H

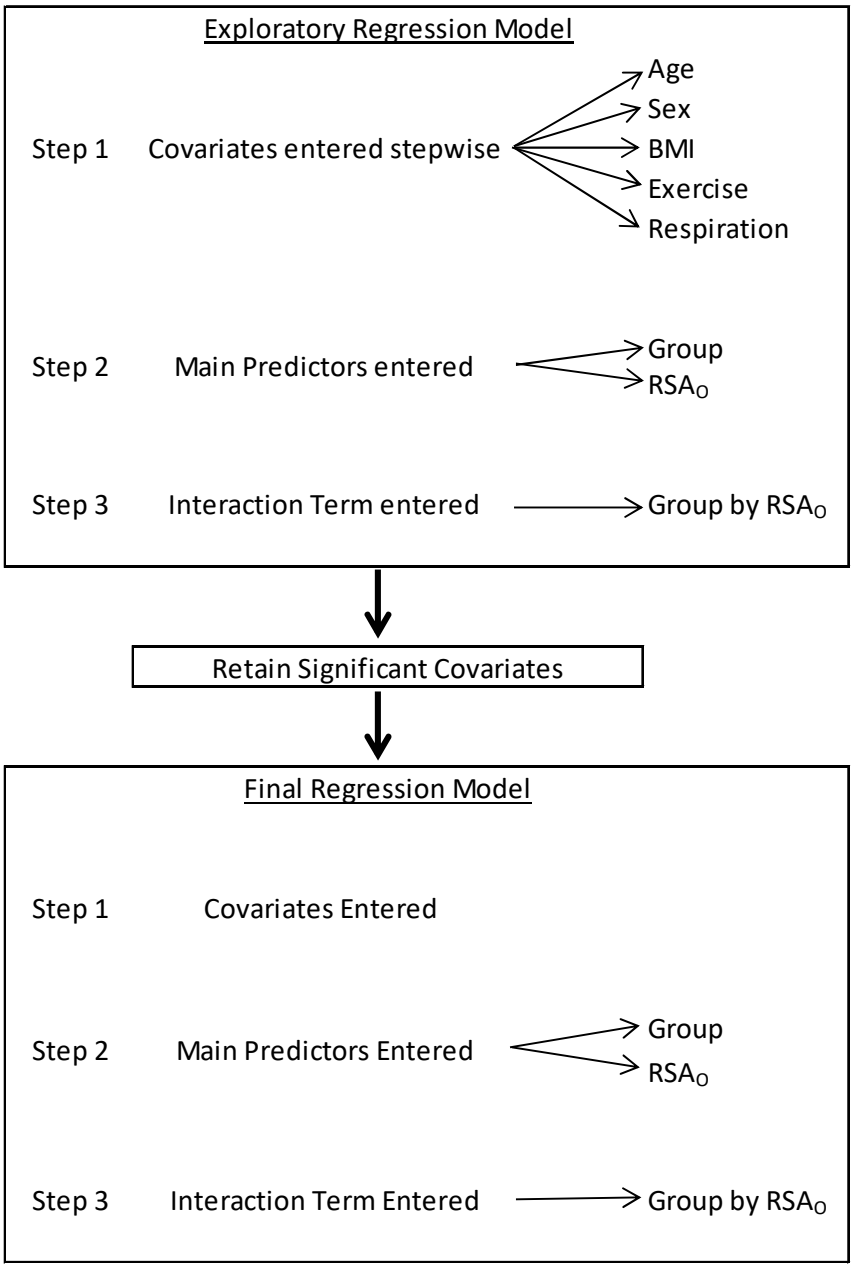
Topographic Map of Locations Relevant to ERP Analysis





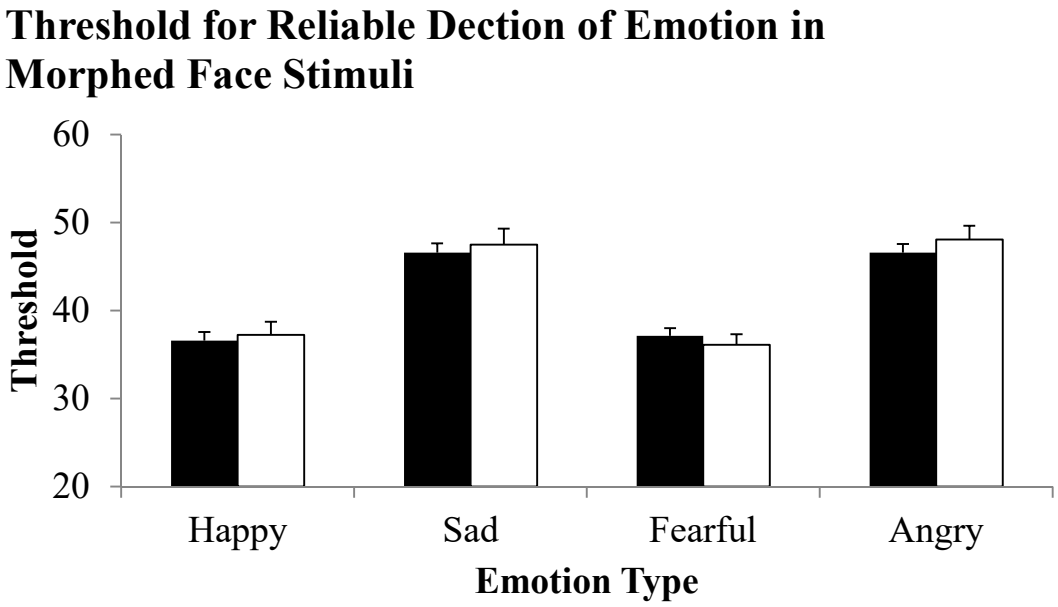
Appendix I

Regression Strategy



Appendix J

Detection of Emotion in Face Stimuli



Participants selected one of five possible responses after presentation of each face during the task: Happy, Sad, Neutral, Fearful, or Angry. They were asked to choose the best descriptor, balancing speed and accuracy. Responses were assessed as the correct emotion identified out of the total number of stimuli in that emotion/intensity category to determine a "percent correct" score. A second "percent emotion" score was calculated as the percentage of responses using one of the emotional descriptors (i.e. non-neutral), in order to examine the intensity of expression present when the participant was able to accurately discriminate between a neutral and emotional face. The figure shows the level of intensity (20 through 60%) at which participants were able to identify the faces as emotional on greater than or equal to 75% of trials. No effect of the experimental condition (SR/Control) was found.

Control = solid bars; SR = open bars.

Appendix K

ERP Trial and Latency Data

Table K1

Emotional Face Task – Number of Trials Included in N170 for Each Emotional Face Category

	Control		SR				
	n	M (SD)	n	M (SD)	*t*	*df*	*p*
Happy	32	67.06 (13.96)	31	63.81 (13.07)	.95	61	.343
Sad	32	52.62 (14.50)	31	46.00 (11.77)	1.99	61	.051
Fearful	32	57.62 (19.26)	32	53.12 (14.53)	1.05	62	.295
Angry	32	56.62 (21.95)	32	49.00 (12.98)	1.69	62	.096

Table K2

Emotional Face Task – Latency of N170 for Each Emotional Face Category

	Control		SR				
	n	M (SD)	n	M (SD)	*t*	*df*	*p*
Happy	32	170.84 (14.98)	31	173.06 (13.30)	-.62	61	.537
Sad	32	169.37 (13.44)	31	173.35 (14.58)	-1.13	61	.264
Fearful	32	169.03 (8.93)	32	172.72 (15.04)	-1.19	62	.239
Angry	32	170.62 (14.92)	32	171.66 (11.57)	-.31	62	.758

Note. Latency in milliseconds.

Table K3

IAPS Emotional Picture Task – Number of Trials Included in LPP for Each Picture Type

	Control		SR				
	n	M (SD)	n	M (SD)	*t*	*df*	*p*
Negative		41.06 (8.33)		38.89 (7.83)	1.14	70	.260
Neutral	36	29.06 (7.31)	36	26.78 (7.50)	1.30	70	.196
Positive		39.00 (7.20)		37.22 (9.49)	.89	70	.374

Appendix L

Correlations between HR and RSA Measures for the Full Sample

	HR_O	HR_M	HR_F	HR_I	Resp.	RSA_O	RSA_M	RSA_F	RSA_I
HR_O	-								
HR_M	.703**	-							
HR_F	.683**	.882**	-						
HR_I	.701**	.829**	.923**	-					
Resp.	.073	-.158	-.098	-.063	-				
RSA_O	-.435**	-.150	-.184	-.162	-.568**	-			
RSA_M	-.386**	-.399**	-.347**	-.288*	-.293*	.717**	-		
RSA_F	-.381**	-.385**	-.503**	-.413**	-.211	.652**	.709**	-	
RSA_I	-.257*	-.357**	-.430**	-.407**	-.207	.573**	.819**	.763**	-

Note. * $p < .05$, ** $p < .01$

Appendix M

Table M1

Regression of HR during Task Performance and Group on Reaction Time (sqrt ms)

Emotion	Step		*B (SE)*	R^2	R^2_{Δ}	*F Change*	*df1*	*df2*	*p*
Sad	1	HR_F	.025 (.06)						
		Group	.511 (.94)	.007	.007	.22	2	64	.80
	2	HR_F * Group	-.354 (.11)*	.140	.133	9.77	1	63	.003*
Angry[a]	1	HR_F	.002 (.05)						
		Group	.41 (.86)	.004	.004	.11	2	64	.89
	2	HR_F * Group	-.25 (.11)*	.082	.079	5.42	1	63	.02*
Happy[a]	1	HR_F	.009 (.05)						
		Group	.88 (.83)	.018	.018	.57	2	64	.57
	2	HR_F * Group	-.14 (.11)	.043	.026	1.70	1	63	.20
Fear[a]	1	HR_F	.01 (.06)						
		Group	.14 (1.00)	.001	.001	.03	2	64	.97
	2	HR_F * Group	-.20 (.13)	.040	.039	2.57	1	63	.11

Note. [a] ANOVA test of regression model non-significant.

Table M2

Regression of HR-Reactivity (Baseline-Task) and Group on Reaction Time (sqrt ms)

Emotion	Step		*B (SE)*	R^2	R^2_{Δ}	*F Change*	*df1*	*df2*	*p*
Sad	1	HRR_F	-.06 (.13)						
		Group	.38 (1.00)	.008	.008	.259	2	62	.77
	2	HRR_F * Group	-.008 (.28)	.008	.0	.001	1	61	.98
Angry	1	HRR_F	-.14 (.12)						
		Group	-.09 (.90)	.024	.024	.770	2	62	.47
	2	HRR_F * Group	-.19 (.25)	.034	.010	.612	1	61	.44
Happy	1	HRR_F	-.08 (.12)						
		Group	.74 (.88)	.025	.025	.787	2	62	.46
	2	HRR_F * Group	-.02 (.24)	.025	.0	.006	1	61	.94
Fear	1	HRR_F	-.09 (.14)						
		Group	-.28 (1.06)	.007	.007	.207	2	62	.81
	2	HRR_F * Group	-.33 (.29)	.028	.021	1.337	1	61	.25

Appendix N

Regression of Group and Baseline RSA on N170 to Emotional Faces

	Step		*B (SE)*	R^2	*F Δ*	*df1*	*df2*	*p (FΔ)*	*F model*	*df*	*P*
Happy PO4	1	Group	4.11 (1.31)*								
		RSA	-3.63 (1.31)*	.22	8.11	2	58	.001*	8.11	2, 58	.001*
	2	Group*RSA	7.31 (2.46)*	.32	8.81	1	57	.004*	9.07	3, 57	<.001*
Sad PO4	1	Group	3.30 (1.29)*								
		RSA	-3.23 (1.29)*	.17	5.88	2	58	.005*	5.88	2, 58	.005*
	2	Group*RSA	4.97 (2.53)†	.22	3.86	1	57	.054†	5.40	3, 57	.002*
Fear PO4	1	Group	3.19 (1.31)†								
		RSA	-2.55 (1.31)*	.13	4.59	2	59	.014*	4.59	2, 59	.014*
	2	Group*RSA	6.95 (2.48)*	.24	7.87	1	58	.007*	6.04	3, 58	.001*
Angry PO4	1	Group	3.54 (1.28)								
		RSA	-2.00 (1.28)*	.14	4.80	2	59	.012*	4.80	2, 59	.012*
	2	Group*RSA	6.31 (2.45)*	.23	6.66	1	58	.012*	5.72	3, 58	.002*
Happy PO6	1	Group	4.31 (1.35)*								
		RSA	-3.42 (1.35)*	.21	7.79	2	57	.001*	7.79	2, 57	.001*
	2	Group*RSA	6.58 (2.58)*	.30	6.50	1	56	.014*	7.86	3, 56	<.001*
Sad PO6	1	Group	3.43 (1.37)*								
		RSA	-3.34 (1.37)*	.17	5.72	2	57	.005*	5.72	2, 57	.005*
	2	Group*RSA	4.03 (2.71)	.20	2.21	1	56	.143	4.62	3, 56	.006*
Fear PO6	1	Group	3.63 (1.29)*								
		RSA	-2.79 (1.29)*	.17	6.00	2	58	.004*	6.00	2, 58	.004*
	2	Group*RSA	6.01 (2.48)*	.25	5.88	1	57	.019*	6.30	3, 57	.001*
Angry PO6	1	Group	3.94 (1.33)								
		RSA	-1.66 (1.33)*	.15	5.02	2	58	.010*	5.02	2, 58	.010*
	2	Group*RSA	4.73 (2.60)†	.19	3.30	1	57	.074†	4.58	3, 57	.006*
Happy PO8	1	Group	3.35 (1.30)*								
		RSA	-3.02 (1.30)*	.16	5.60	2	58	.006*	5.60	2, 58	.006*
	2	Group*RSA	6.61 (2.46)*	.26	7.19	1	57	.010*	6.53	3, 57	.001*
Sad PO8	1	Group	2.50 (1.33)*								
		RSA	-2.92 (1.33)†	.12	3.87	2	58	.026*	3.87	2, 58	.026*
	2	Group*RSA	3.18 (2.65)	.14	1.44	1	57	.235	3.08	3, 57	.035*
Fear PO8	1	Group	2.95 (1.24)†								
		RSA	-2.13 (1.24)*	.12	4.04	2	59	.023*	4.04	2, 59	.023*
	2	Group*RSA	5.42 (2.41)*	.19	5.07	1	58	.028*	4.57	3, 58	.006*
Angry PO8	1	Group	3.10 (1.29)								
		RSA	-1.18 (1.29)*	.10	3.15	2	59	.050*	3.15	2, 59	.050*
	2	Group*RSA	3.84 (2.56)	.13	2.24	1	58	.140	2.89	3, 58	.043*

Note. B values are the unstandardized coefficients at entry into the model.
Independent variables were coded -.5/.5 for Control/SR and Low/High RSA (median split) respectively.
* = $p < .05$, † $p = < .10$

Appendix O

Table O1

Correlation Table N170 Amplitude to Emotional Faces with Cardiac Measures

	Control											
	Happy			Sad			Fearful			Angry		
	PO4	PO6	PO8	PO4	PO6	PO8	PO4	PO6	PO8	PO4	PO6	PO8
HR O	-0.297	-0.139	-0.039	**-.398***	-0.269	-0.176	-0.248	-0.196	-0.122	-0.098	-0.088	-0.066
HR M	-0.246	-0.138	-0.083	-0.275	-0.21	-0.141	-0.155	-0.135	-0.069	0.029	0.02	0.025
HR F	-0.231	-0.082	-0.083	**-0.304†**	-0.176	-0.138	-0.24	-0.164	-0.136	-0.059	-0.023	-0.066
HRR F	0.005	0.111	-0.012	-0.096	0.051	-0.012	-0.198	-0.079	-0.155	-0.19	-0.094	-0.203
RSA O	0.068	0.106	-0.01	0.045	0.049	-0.009	0.029	0.062	-0.022	0.041	0.085	0.017
RSA M	-0.031	0.091	0.042	-0.002	0.063	0.048	-0.036	0.082	0.026	-0.099	-0.025	-0.066
RSA F	0.165	0.207	0.125	0.010	0.076	0.032	0.104	0.149	0.069	0.022	0.072	0.034
RSAR F	0.246	0.169	0.122	0.027	0.055	0.013	0.15	0.092	0.067	0.100	0.110	0.130
	Sleep Restricted											
	Happy			Sad			Fearful			Angry		
	PO4	PO6	PO8	PO4	PO6	PO8	PO4	PO6	PO8	PO4	PO6	PO8
HR O	-0.123	-0.187	-0.182	-0.016	-0.104	-0.105	-0.047	-0.156	-0.154	-0.115	-0.178	-0.162
HR M	0.02	-0.046	-0.103	0.164	0.087	0.070	0.096	0.003	-0.035	-0.041	-0.076	-0.136
HR F	-0.174	-0.234	-0.231	-0.074	-0.136	-0.110	-0.145	-0.235	-0.223	-0.247	-0.273	-0.268
HRR F	-0.238	-0.253	-0.148	**-0.369†**	**-.385***	-0.321	-0.26	-0.252	-0.184	-0.213	-0.252	-0.177
RSA O	**0.332†**	0.300	0.262	0.209	0.172	0.121	0.284	0.284	0.230	0.289	0.268	0.199
RSA M	0.327	0.316	**0.348†**	0.091	0.109	0.118	0.259	0.291	0.303	0.291	**0.314†**	**0.352†**
RSA F	**0.342†**	**0.336†**	0.297	0.172	0.205	0.161	0.299	**0.337†**	0.300	**0.330†**	**0.340†**	**0.321†**
RSAR F	0.044	0.068	0.029	0.107	0.156	0.130	0.065	0.087	0.077	0.084	0.086	0.069

Note. * Correlation is significant at the 0.05 level (2-tailed). † Trend at the 0.10 level (2-tailed).

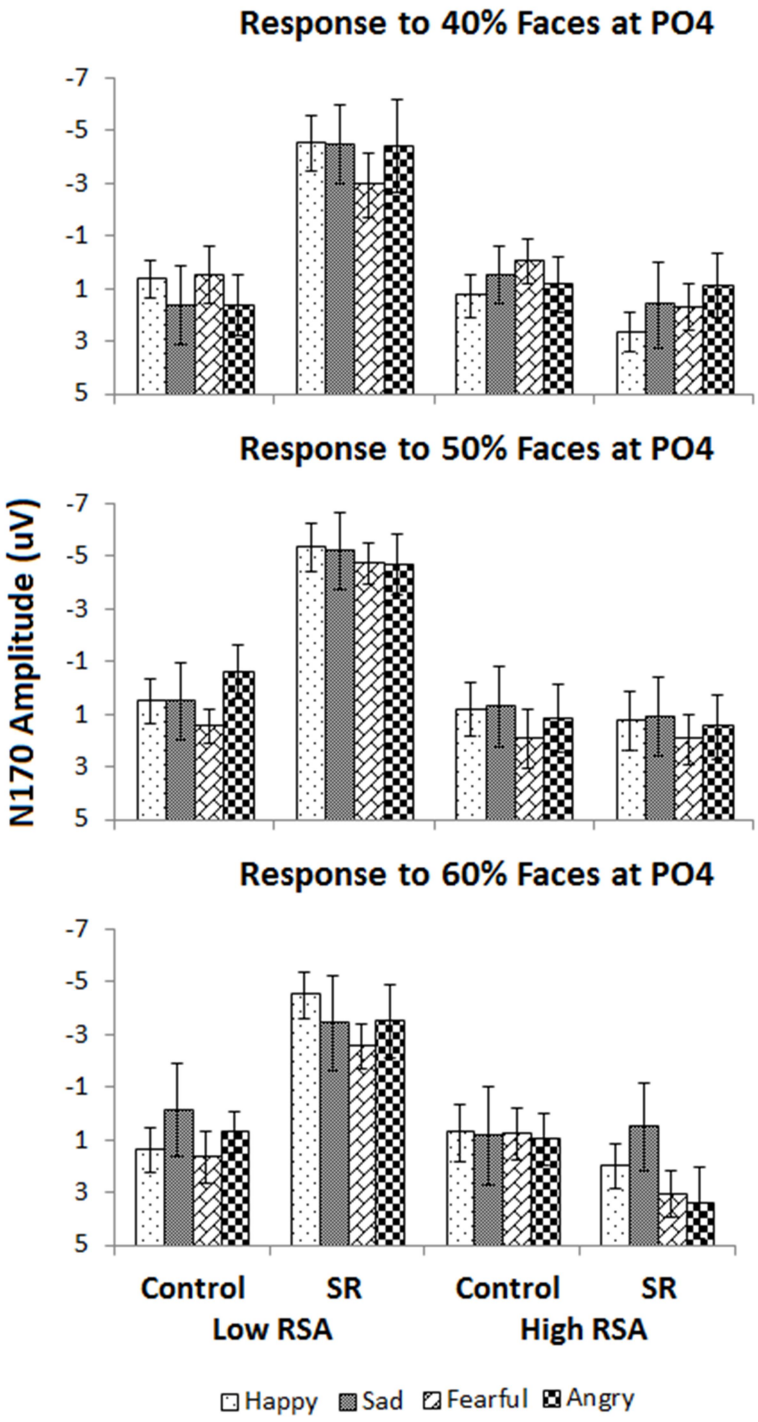
Table O2

Correlation Table LPP to Emotional Pictures (IAPS) with Cardiac Measures

	Control									
	Negative		Netural		Positive		Negative-Neutral		Positive-Neutral	
	CZ	CPZ	CZ	CPZ	CZ	CPZ	CZ	CPZ	CZ	CPZ
HR O	0.073	0.047	0.003	-0.019	0.148	0.105	0.119	0.103	0.248	0.189
HR M	-0.033	-0.060	-0.049	-0.090	-0.017	-0.071	0.032	0.047	0.069	0.048
HR F	0.064	0.022	0.020	-0.035	0.167	0.083	0.072	0.087	0.245	0.183
HRR F	0.135	0.125	0.097	0.078	**0.314†**	0.288	0.059	0.076	**.359***	**0.297†**
RSA O	-0.122	-0.149	-0.112	-0.143	-0.112	-0.088	-0.008	-0.010	0.026	0.113
RSA M	-0.030	-0.052	0.018	-0.005	0.028	0.043	-0.085	-0.076	0.013	0.074
RSA F	-0.129	-0.178	-0.021	-0.057	-0.110	-0.096	-0.182	-0.187	-0.146	-0.047
RSAR F	-0.027	-0.085	0.094	0.057	-0.090	-0.132	-0.218	-0.221	-0.341	-0.295
	Sleep Restricted									
	Negative		Netural		Positive		Negative-Neutral		Positive-Neutral	
	CZ	CPZ	CZ	CPZ	CZ	CPZ	CZ	CPZ	CZ	CPZ
HR O	0.134	0.124	-0.165	-0.075	0.030	0.009	**.338***	0.247	0.172	0.074
HR M	0.099	0.170	0.005	0.208	-0.071	0.023	0.117	0.010	-0.078	-0.157
HR F	0.196	0.177	0.017	0.212	0.190	0.184	0.224	0.008	0.180	0.006
HRR F	0.163	0.033	0.025	0.003	**.411***	0.263	0.174	0.043	**.400***	0.269
RSA O	-0.067	0.075	0.108	0.220	-0.119	0.028	-0.195	-0.132	-0.215	-0.162
RSA M	-0.233	-0.067	-0.168	-0.113	-0.183	-0.024	-0.110	0.030	-0.044	0.073
RSA F	-0.214	-0.049	-0.128	-0.165	**-0.333†**	-0.224	-0.125	0.114	-0.230	-0.088
RSAR F	-0.009	-0.042	0.050	-0.120	-0.275	**-.379***	-0.065	0.075	**-0.325†**	-0.286

Note. * Correlation is significant at the 0.05 level (2-tailed). † Trend at the 0.10 level (2-tailed).

Appendix P



N170 Amplitude for the 40, 50 and 60% Face Stimuli by Group and High/Low RSA.

Appendix Q

Emotion Regulation Questionnaire (ERQ; Gross & John, 2003)

Questionnaire 2:
Instructions and Items

We would like to ask you some questions about your emotional life, in particular, how you control (that is, regulate and manage) your emotions. The questions below involve two distinct aspects of your emotional life. One is your emotional experience, or what you feel like inside. The other is your emotional expression, or how you show your emotions in the way you talk, gesture, or behave. Although some of the following questions may seem similar to one another, they differ in important ways. For each item, please answer using the following scale:

1----------2----------3----------4----------5----------6----------7
strongly disagree **neutral** **strongly agree**

1. ____ When I want to feel more *positive* emotion (such as joy or amusement), I *change what I'm thinking about*.
2. ____ I keep my emotions to myself.
3. ____ When I want to feel less *negative* emotion (such as sadness or anger), I *change what I'm thinking about*.
4. ____ When I am feeling *positive* emotions, I am careful not to express them.
5. ____ When I'm faced with a stressful situation, I make myself *think about it* in a way that helps me stay calm.
6. ____ I control my emotions by *not expressing them*.
7. ____ When I want to feel more *positive* emotion, I *change the way I'm thinking* about the situation.
8. ____ I control my emotions by *changing the way I think* about the situation I'm in.
9. ____ When I am feeling *negative* emotions, I make sure not to express them.
10. ___ When I want to feel less *negative* emotion, I *change the way I'm thinking* about the situation.

Appendix R

Regression of Group on N170 by Emotion, Moderated by ERQ-S, ERQ-R, and RSA

	Step		*B (SE)*	R^2	*F Δ*	*df1*	*df2*	*p*	*F*	*df*	*p*
Happy	1	‡									
	2	Grp	-4.10 (1.31)*								
		RSA	3.65 (1.31)*								
		ERQ-R	-.16 (.13)								
		ERQ-S	.47 (.14)*	.37	7.16	4	49	<.001*	7.16	4, 49	<.001*
	3	Grp*RSA	7.41 (2.20)*								
		ERQ-R*RSA	.58 (.22)*								
		ERQ-S*Grp	.58 (.23)*								
		ERQ-R*Grp	-.58 (.22)*	.62	7.25	4	45	<.001*	9.03	8, 45	<.001*
	4	ERQ-R*									
		RSA*Grp	1.02 (.42)*	.66	5.98	1	44	.019*	9.58	9, 44	<.001*
Sad	1	Age	.57 (.26)*	.08	4.85	1	52	.032*	4.85	1, 52	.032*
	2	Grp	-3.20 (1.39)*								
		RSA	3.23 (1.35)*								
		ERQ-R	-.16 (.14)								
		ERQ-S	.34 (.14)*	.32	4.07	4	48	.006*	4.45	5, 48	.002*
	3	Grp*RSA	6.44 (2.34)*								
		ERQ-R*RSA	.65 (.24)*								
		ERQ-S*Grp	.64 (.24)*								
		ERQ-R*Grp	-.64 (.25)*	.56	6.07	4	44	.001*	6.22	9, 44	<.001*
	4	ERQ-R*									
		RSA*Grp	.85 (.47)†	.59	3.32	1	43	.075	6.22	10, 43	<.001*
Fear	1	‡									
	2	Grp	-3.13 (1.37)*								
		RSA	2.86 (1.37)*								
		ERQ-R	-.19 (.14)								
		ERQ-S	.40 (.15)*	.26	4.39	4	50	.004*	4.39	4, 50	.004*
	3	Grp*RSA	7.30 (2.24)*								
		ERQ-R*RSA	.90 (.22)*								
		ERQ-S*Grp	.56 (.23)*								
		ERQ-R*Grp	-.57 (.23)*	.57	8.38	4	46	<.001*	7.68	8, 46	<.001*
	4	ERQ-R*									
		RSA*Grp	.82 (.44)†	.60	3.45	1	45	.070†	7.58	9, 45	<.001*
Angry	1	‡									
	2	Grp	-2.02 (1.26)								
		RSA	2.32 (1.25)†								
		ERQ-R	-.21 (.13)								
		ERQ-S	.33 (.14)*	.21	3.11	4	48	.024*	3.11	4, 48	.024*
	3	Grp*RSA	6.84 (2.02)*								
		ERQ-R*RSA	.78 (.20)*								
		ERQ-S*Grp	.49 (.22)*								
		ERQ-R*Grp	-.61 (.21)*	.55	8.52	4	44	<.001*	6.78	8, 44	<.001*
	4	ERQ-R*									
		RSA*Grp	.98 (.39)*	.61	6.45	1	43	.015*	7.49	9, 43	<.001*

Note. ‡ signifies no covariates were retained in the model. B values are the unstandardized coefficients at entry into the model. Independent variables were coded -.5/.5 for Control/SR and Low/High RSA (median split) respectively.
* = $p < .05$, † $p = < .10$